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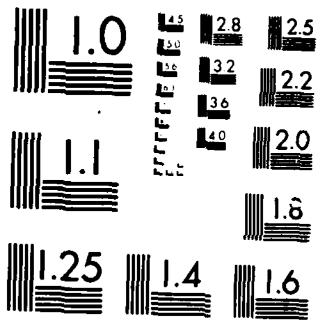

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APPLIED MARINE RESEARCH LABORATORY
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA 23508

MICROCOSM EVALUATIONS OF SEDIMENTS FROM THE PORT OF HAMPTON ROADS, VIRGINIA

By

Raymond W. Alden, III
Arthur J. Butt
Susanne S. Jackman
Guy J. Hall
Robert J. Young, Jr.

Final Report
For Period Ending December 1984

Prepared for the
Department of the Army
Norfolk District, Corps of Engineers
Fort Norfolk, 803 Front Street
Norfolk, Virginia 23510

Under Contract
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Microcosm experiments were conducted to assess quality of Port of H.R. sediments. Zooplankton and benthos were exposed to dredged materials under simulated dump conditions. Changes in community structure, water quality and body burdens of toxins were measured. None of the treatments produced a significant impact on the zooplankton communities. The benthic community studies indicated that most of the taxa observed survived all treatment. Body burden studies indicated that biota exposed to all of the dredged materials did not significantly accumulate heavy metals.

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MICROCOSM EVALUATIONS OF SEDIMENTS FROM THE PORT OF HAMPTON ROADS, VIRGINIA

By

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INTRODUCTION

Dredging operations are vital to the maintenance of seaports. Unfortunately, the sediments from urban estuaries may be highly contaminated. Pollutants introduced directly or indirectly into the waters of these ecosystems are generally partitioned into, and concentrated in the sediments. Therefore, a problem of major concern to port cities is how potentially toxic dredged materials can be disposed with the least possible ecological damage.

A great deal of attention has been focused upon the feasibility of open ocean disposal of dredged materials. In order for ocean sites to be an ecologically sound alternative, the potential

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*Director, Applied Marine Research Laboratory, Old Dominion University, Norfolk, Virginia.

**Manager, Applied Marine Research Laboratory, Old Dominion University, Norfolk, Virginia.

***Research Assistant, Department of Oceanography, Texas A&M University, College Station, Texas.

****Research Assistant, Applied Marine Research Laboratory, Old Dominion University, Norfolk, Virginia.

*****Research Associate, Applied Marine Research Laboratory, Old Dominion University, Norfolk, Virginia.

impacts of open water disposal of dredged sediments must be assessed on a site-to-site basis. Static bioassays (toxicity tests) conducted on standard "test species" are the most common means for biologically evaluating sediments destined for ocean disposal. However, the effectiveness of static bioassay techniques for assessing the potential ecological impacts of ocean disposal of dredged materials is open to question.

Static bioassays employing standard test species are subject to the criticism that conditions are not realistic enough to adequately test the potential adverse effects on biota endemic to a disposal site. Critics of bioassays point out that most standard test species must be relatively hardy in order to be cultured/maintained in the laboratory. Therefore, they may be less sensitive than communities actually living in the vicinity of the disposal site. Moreover, single species static bioassays do not allow an assessment of subtle effects of dredged materials on such dynamic processes as competition, predation, feeding activity, etc. Even the biological uptake of toxins have been shown to be lower for static test conditions than for those which closely simulate the natural environment (Alden et al., 1985a).

Recognizing the limitations of static tests, multiple species microcosms have been developed for use as a confirmation of the relative quality of sediments (or sediment composites) being considered for ocean disposal. The microcosms have been designed to simulate field conditions. Indigenous plankton and benthic communities from the disposal site are introduced into large experimental chambers. Physical parameters such as currents illumination and photoperiods are controlled to simulate natural

conditions in the areas from which the biota are collected. The surface to volume ratio of the benthic habitat to the water column is the same as that of the disposal site. Through this experimental design, a very extensive data set can be accumulated for the comparison of the water quality, plankton community structure, benthic community structure and bioaccumulation potential of toxins in control and experimental tanks.

The present study represents an assessment of the potential ecological effects of dredged materials utilizing multiple species microcosms. The sediments were taken from potential dredge sites located throughout Hampton Roads, Virginia. These sites had been previously tested with traditional lethal bioassays (Alden et al., 1981; Alden and Young, 1982; Alden and Young, 1984) and sublethal bioassays (Alden et al., 1981; Alden et al., 1984a), so these microcosm experiments were designed to represent a means of confirming the relative quality of the sediments under more ecologically realistic conditions.

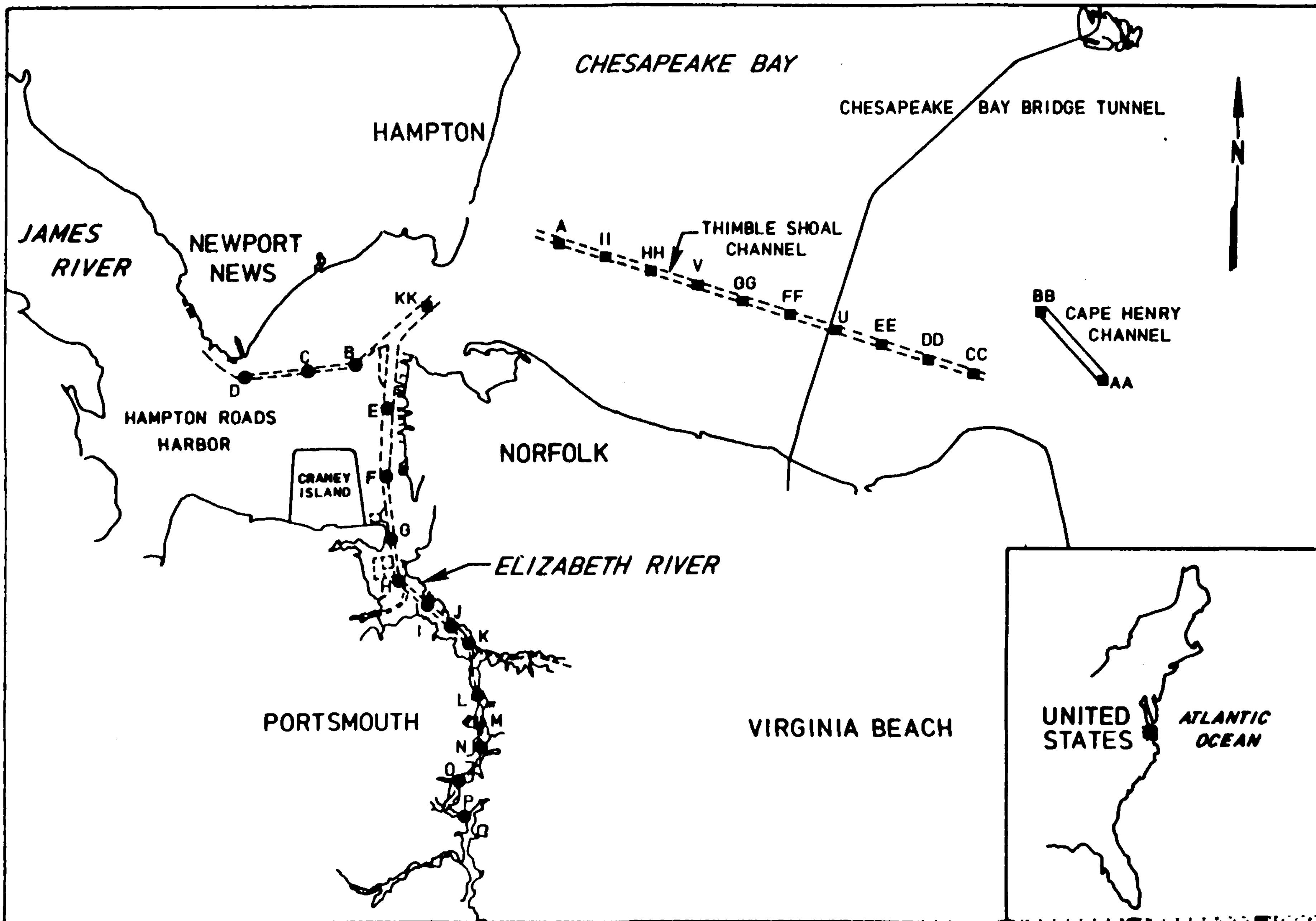
METHOD AND MATERIALS

Study Area

The Port of Hampton Roads, Virginia, contains one of the largest natural harbors in the world. The Port is located within a major metropolitan area that includes the cities of Norfolk, Portsmouth, Chesapeake, Virginia Beach, Newport News and Hampton (Fig. 1a). Hampton Roads and the surrounding estuarine systems provide the setting for one of the most highly industrialized coastal areas on the eastern seaboard of the United States, as well as the largest military port in the world. The Norfolk District of the U.S. Army Corps of Engineers (COE) is responsible for maintaining the navigational channels of this seaport system in order to insure the safe passage of military and commercial vessels. On the average, $4.1 \times 10^6 m^3$ of sediment are dredged annually by the COE. Approximately 60% of the sediments are classified as mud, clay and silt, taken primarily from the urbanized Hampton Roads Harbor/Elizabeth River complex (Figs. 1a,b). The remainder of the dredged materials consist of sand, gravel and shell which is dredged mainly from the Thimble Shoal Channel in the Chesapeake Bay (Pequegnat et al., 1978).

The sediments to be evaluated in the microcosms were composited from various stations to represent major dredge project regions within the Port: Stations CC, DD, EE, U, FF, GG, V, HH, II and A in Thimble Shoal Channel (designated TS); Stations KK, B, C, D, and E in Hampton Roads Harbor (HR); Stations F, G, H, I, J in the Elizabeth River Mainstem (EMS); and Stations M, N, and O in the Southern Branch of the Elizabeth River (SB) (Fig. 1a).

Figure 1a. The Port of Hampton Roads, Virginia: general study area.



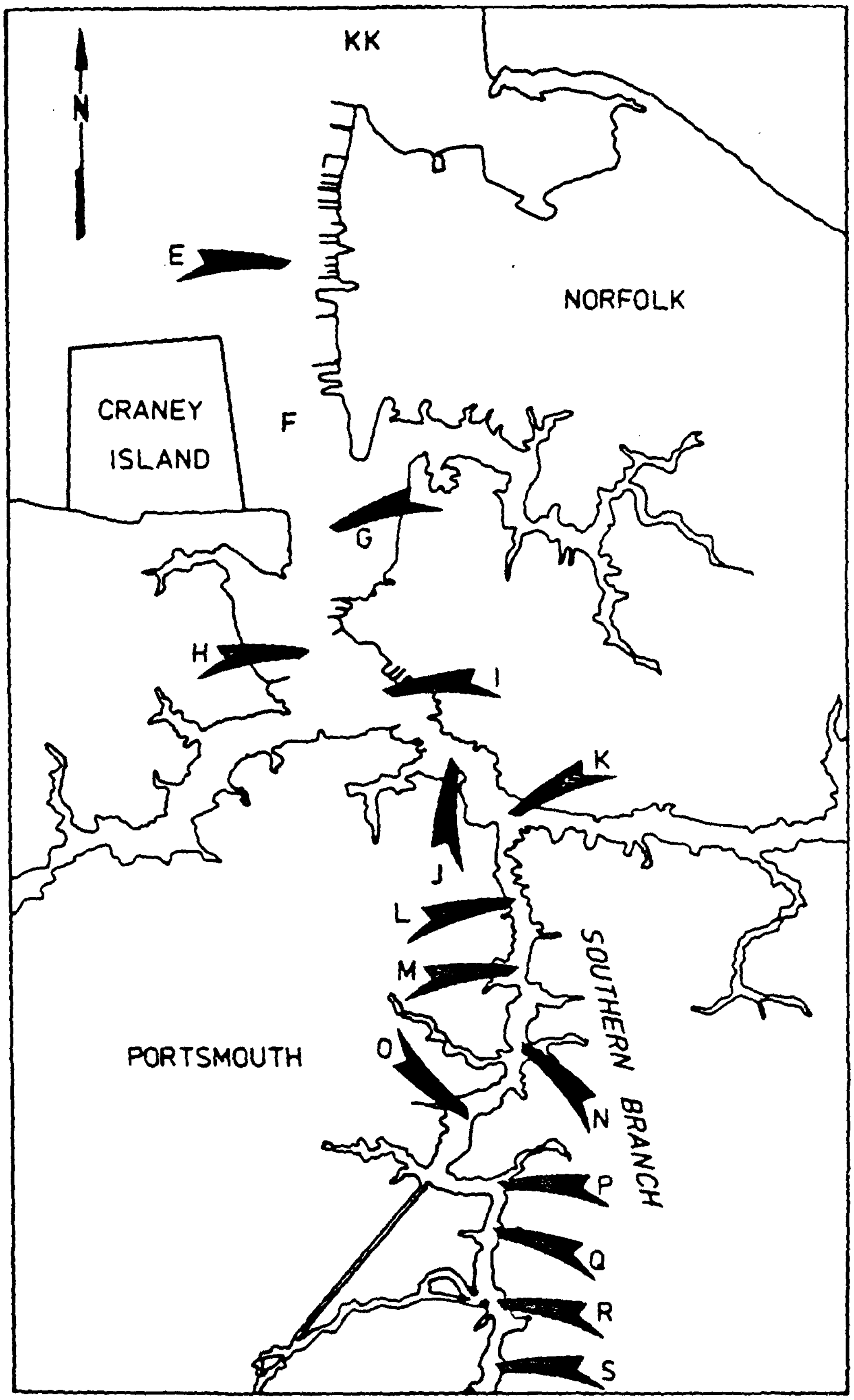


Figure 1b. The Port of Hampton Roads, Virginia: Southern Branch of the Elizabeth River.

Field Methods

The experiments were run in two series: microcosm #1 (1982) testing the HR sediments; and microcosm #2 (1983) testing the sediments from EMS, TS, and SB. The sediments from SB were previously tested in microcosms prior to dredging (Alden et al., 1981) and nine months following maintenance dredging (Alden et al., 1985a). Therefore, the SB tests were conducted to determine whether the previously observed ecological effects of the "contaminated" sediments of this region returned during the 18 months following dredging operations.

In addition, controls were established with "clean" sediments simulating "test dumps." Sediments from the proposed Norfolk Disposal Site (NDS) were used in the controls for microcosm #1. Sediments for the control treatment in microcosm #2 were taken from a non-industrialized estuary on the Eastern Shore near Cape Charles, Virginia. These control sediments were selected to be similar in physical characteristics (particle size, organic content) to the silt/clays previously observed in the "inner harbor" regions of the Port.

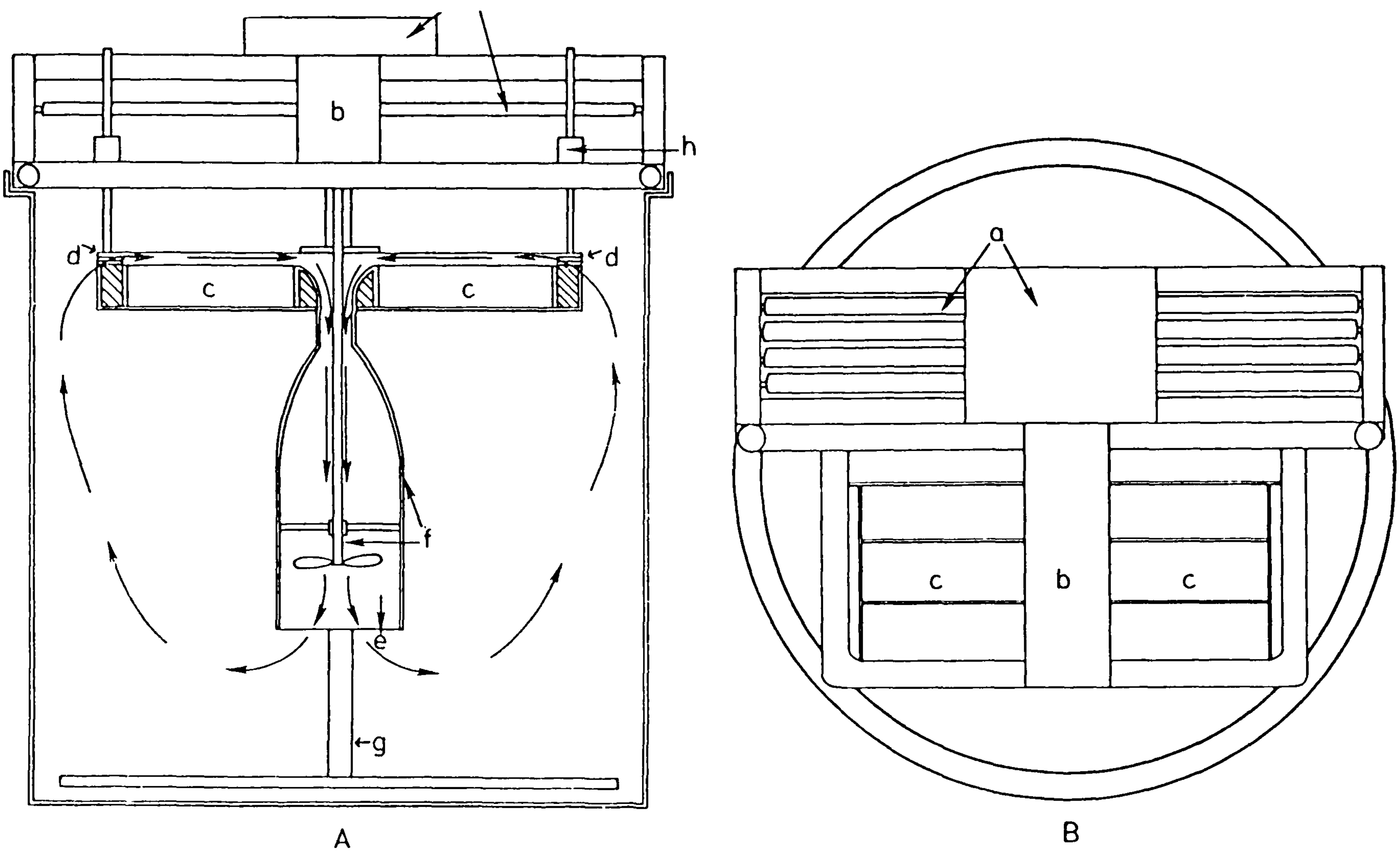
Sediments were collected at each of the stations with a stainless steel Pearce bucket dredge fitted with a 18 liter polyethylene insert container. Following collection, the inserts were fitted with "snap-tops" and maintained at 4°C for transport to the laboratory. Prior to testing, the sediments were frozen for at least 48 hours to kill the indigenous benthic communities.

Microcosm Methods

Microcosms were performed in 1500 liter polyethylene barrels, filled with natural seawater and maintained at 20°C with a 14:10 day/night cycle. The barrels contained two benthic trays, each with three chambers, and an additional tray for a population of hard shell clams (**Mercenaria mercenaria**) which were used in the bioaccumulation experiments (Fig. 2). The size of the benthic chambers ($0.035m^2$) was based upon a species-area curve evaluation of the minimum area required to represent the benthic communities found in the vicinity of the NDS (Dr. D.M. Dauer, personal communication). The volume of the microcosms was based upon the bottom area to water column volume ratio found at the NDS, assuming "worst case" stratification (i.e. a pycnocline 10m above the bottom restricts bottom exchange processes to the hypolimnion).

Two types of water circulating devices were operational in each barrel. One system circulated the water column of the barrel to simulate oceanic currents and to maintain the plankton in suspension. The second device drew water over the benthic trays to simulate epibenthic circulation. A "honeycomb" bank of 0.5cm diameter plastic tubes were placed in the inflow ports of the benthic chambers to laminarize the flow and prevent turbulent erosion patterns. The speed of the currents in the benthic chambers was calibrated to approximately 4cm/s, the average near-bottom current velocity at NDS (Dr. D.P. Wang, personal communication). Photocouple devices connected to the circulating systems allowed the remote monitoring and calibration of current velocities. Fluorescent lights were adjusted to simulate the

Figure 2. Microcosm chamber (A. x-sectional view; B. plane view) with lightbank (a), circulation motor (b), sediment holding trays (c), water inflow channel (d), tray circulation outflow (e), tray circulation rotor (f), barrel circulation rotor (g), and tray support screws for adjusting tray depth in barrel.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field light intensities observed 1m below the surface at the time of collection. The benthic chambers were covered with darkened plexiglass to prevent the light intensities from disrupting benthic activities.

Sediment samples with their indigenous benthic communities were collected with the Pearce dredge at the NDS. The sediments were randomly distributed into the benthic chamber trays which were transported in coolers containing seawater. The raw seawater was collected in the coastal waters off the mouth of the Chesapeake Bay. The seawater was collected by "dunking" pairs of 220 liter screw-top plastic drums in a "holder" suspended from a crane on the barge. Zooplankton tows were also taken to enrich the barrels with animals which may have avoided capture during the "dunking" process. Both the benthic and plankton samples were aerated and maintained at collection temperatures during transport to the laboratory. The seawater and plankton samples were equally distributed among the microcosm barrels by a gravity-flow ducting system designed to minimize organismal damage. The benthic communities were also placed into the microcosm barrels and the systems were allowed to equilibrate for 96 hours. Defaunated NDS sediments were placed in the additional trays along with a population of clams for the bioaccumulation experiments. After equilibration, defaunated test sediments were dumped on top of benthic and clam trays. After the dump, the benthic trays were closed into the chambers and not disturbed further until the end of the experiment.

The water quality of all microcosm barrels was monitored daily. Triplicate measurements were taken from each barrel for the following water quality parameters: temperature (^oC), salinity (ppt), dissolved oxygen (DO), pH, suspended solids (SS), volatile nonfilterable residue (VNR), turbidity, nitrates (NO_3), nitrites (NO_2), ammonia (NH_3), total Kjeldahl nitrogen (TKN), orthophosphates (OPO_4), total phosphorous (TP), chlorophyll a, chlorophyll b, chlorophyll c, and phaeophytin. Water samples were analyzed for metals (Cd, Cu, Fe, Hg, Mn, Ni, Pb, Zn) immediately prior to the simulated dump, four hours after the dump and at the end of the 10-day experimental period.

Following the 10-day experimental period, the benthic organisms were harvested by sieving, preserved in formalin-rose bengal, sorted, identified and counted. The zooplankton communities were sampled by rapidly pulling a 3" diameter Wisconsin style plankton net (150 micron mesh) from the bottom to the surface of the microcosm barrels. The harvested clams were purged in clean seawater for 24 hours and frozen until analyzed for toxins.

During microcosm #1, the indigenous benthic fauna were analyzed for heavy metals. Following identification and counting, the organisms from each tray were sorted into the taxonomic groups (at the phylum level) and processed for heavy metals analysis. Sample blanks of the preserving agents were analyzed to eliminate them as a potential source of metal contamination. The samples were sorted and stored with acid-washed plastic implements (forceps, trays, vials) to also prevent contamination.

Chemical Analyses

The physiochemical water quality parameters monitored in the microcosms were analyzed according to methods described by U.S. Enviromental Protection Agency (EPA, 1979) or the American Public Health Association (APHA, 1979). Temperature, salinity, dissolved oxygen, pH and turbidity were measured by probes. Concentrations of NH_3 and TKN were determined by micro-Kjeldahl techniques, steam distillation and nesslerization. Nitrates were determined by the cadmium reduction method and nitrites were analyzed by the sulfanilic acid method. Samples analyzed for TP were digested by the persulfate method to oxidize all forms of phosphorous to the OPO_4 form. The OPO_4 levels were determined by colorimetric reactions with ammonium molybdate and potassium antimonyl tartrate. The plant pigments were measured and calculated by the UNESCO method (Strickland and Parsons, 1974). Metals in the water were determined by atomic absorption spectrometry (AAS) following MIBK/APDC preconcentration. Mercury was determined by cold vapor techniques of AAS or by a mercury analyzer.

The biological tissues (benthic phyla in microcosm #1, clams in microcosm #2) analyzed for metals were dried at 60°C and weighed. The samples were then wet ashed using HNO_3 and H_2O_2. The digestates were brought to volume with deionized water and stored in polyethylene bottles. The samples were analyzed by flame or flameless AAS, depending upon the range of concentrations observed for each metal.

Chlorinated hydrocarbons (CHC's) were analyzed in the clams from microcosm #1. The CHC's were analyzed according to the methods described by EPA (1980a). The clams in the microcosm #2

experiments were analyzed for polynuclear aromatic hydrocarbons (PNAH's), the major organic contaminants of the "inner harbor" region. The PNAH analyses were conducted according to the method described by EPA (1980b). The extracts of the samples for organic toxin analysis were analyzed on capillary gas chromatography systems fitted with ECD's or FID's (as appropriate) and data microprocessors.

RESULTS

Water Quality Effects

The monitoring of the water quality in microcosm #1 commenced on the day before the simulated dump. The temperature of the seawater upon introduction into the microcosm barrels was approximately 23°C. The temperatures were slowly dropped to 20°C during the acclimation period and the temperatures were maintained within 1°C of this value throughout the experiment. The salinity of the seawater was approximately 23.5 ppt, a value which was maintained within ± 1 ppt for the duration of the experiments. The results of the remaining water quality analyses are presented in Figs. A1-A28 of Appendix A.

As would be expected, the turbidities of the microcosm barrels increased immediately following the dump, with the finer HR sediments producing a greater effect than the coarser NDS control sediments (Fig. A1). However, the turbidities returned to pre-dump levels within the first 48 hours following the dump and the differences between the treatments appeared to be negligible thereafter. Likewise, the SS and VNR levels in the barrels increased following the dump and then decreased over the next two days (Figs. A2, A3). However, the SS and VNR increased between days 3-6 and leveled off at concentrations that were 2 to 3 times the pre-dump values. It is believed that this pattern was due to a phytoplankton bloom observed in the tanks during the same period (see below).

The nutrient levels in the barrels were quite low. In fact, nitrite and orthophosphate concentrations were below detection

limits throughout the experiments. Nitrate levels were only above detection limits after day 5 (Fig. A4). Ammonia and TKN concentrations were quite high immediately before the dump and the levels appeared to be only slightly elevated by the introduction of the "dredged materials" into the systems (Figs. A5, A6). The values then dropped through day 6, after which they appeared to exhibit daily fluctuations. The TP values in both treatments were elevated by the dump, but concentrations rapidly dropped within 48 hours (Fig. A7). Thereafter, the TP concentrations appeared to cycle around the pre-dump levels.

The chlorophyll _a_ levels prior to the dump were quite low (Fig. A8). On the other hand, the relative values of chlorophyll _b_ and chlorophyll _c_ were somewhat higher than expected by their "typical" ratios to chlorophyll _a_ during this period (Figs. A9, A10). Phaeophytin was also at its peak during this period. During the days following the dump a phytoplankton bloom occurred, as evidenced by the increased levels of chlorophyll _a_ which peaked at day 4 in both treatments (Fig. A11). Chlorophyll _b_, chlorophyll _c_ and phaeophytin exhibited an inverse pattern declining during the period of maximum chlorophyll _a_ concentrations and only increasing when bloom conditions began to tail off.

The DO and the pH exhibited cycles which could be explained in terms of the nutrient-phytoplankton patterns (Figs. A12, A13). These levels were quite high prior to the dump, and the immediate effects associated with the introduction of the simulated dredged materials appeared to be negligible. However, DO and, to a lesser

extent, pH values dropped during the next five days. The values then increased to higher levels from day 6 to the end of the experiment. It should be noted that the range of pH values was less than 0.5 units throughout the cycle and the DO values never dropped below 6.0 ppm. Therefore, the cycling of these parameters did not appear to represent an ecologically adverse pattern.

The water quality data was subjected to multivariate analysis of covariance (MANCOVA) to determine whether there were any overall responses which could be attributed to treatment effects once the time (day-to-day) effects have been taken into account. In order to fit the various types of cycling observed in the water quality parameters, a fourth order model was employed (i.e. day taken from a power of 1 to a power of 4). The results of the time-corrected treatment models (i.e. essentially a multivariate analysis of variance or MANOVA once the covariate effects of time have been accounted for) are presented in Table 1. A highly significant treatment effect was indicated ($p < 0.0001$). The univariate contrasts indicated that turbidity and suspended solids were significantly higher in the HR barrels, while NH_3 was higher in the control tanks. However, an examination of the patterns of these parameters (Figs. A1, A2 and A5) indicates that the differences caused by the simulated disposal operations are extremely transient, disappearing within the first 48 hours.

The monitoring of microcosm #2 began 72 hours prior to the dump. Temperatures were maintained at $20^{o}C \pm 1^{o}C$ and salinities were 25 ppt ± 1 ppt. The results of monitoring the remaining physicochemical parameters are presented in Appendix A, Figs. A14-A28.

TABLE 1. Statistical tests of time-corrected treatment effects on water quality. The results of the univariate tests presented are those that were significantly (α=0.01) different from control conditions (NS = no significantly different).

Experiment	Period	MANOVA	Univariate Treatment-Parameter Combinations
I. Microcosm #1:			
A. Physiochemical parameters	Before dump (Day 0)	Wilk's = 0.35 F = 1.71 d.f. = 11, 12 p = 0.19	N.S.
	After dump (Corrected for time effects)	Wilk's = 0.67 F = 9.33 d.f. = 12, 223 p = <0.0001	Hampton Roads: Turbidity↑ S.S.↑ NH_3↓
B. Metals	Before dump (Day 0)	Wilk's = 0.84 F = 1.20 d.f. = 3, 19 p = 0.34	N.S.
	After dump (Day 0)	Wilk's = 0.09 F = 71.12 d.f. = 3, 20 p = <0.0001	Hampton Roads: Fe↑
	End (Day 10)	Wilk's = 0.28 F = 16.73 d.f. = 3, 20 p = <0.0001	Hampton Roads: Zn↓
II. Microcosm #2:			
A. Physiochemical parameters	Before dump (Day 0)	N/A*	N.S.
	After dump (corrected for time effects)	Wilk's = 0.13 F = 27.11 d.f. = 27, 725 p = <0.0001	Southern Branch: Chl a↓ NO_3↑ NO_2↑ OPO_4↑ D.O.↓ pH↓ Elizabeth River Mainstem: Chl a↑ NO_3↑ NO_2↑ OPO_4↓ D.O.↑ pH↑
B. Metals	Before dump (Day 0)	Wilk's = 0.17 F = 1.67 d.f. = 21, 41 p = 0.081	N.S.
	After dump (Day 0)	Wilk's = 0.15 F = 2.25 d.f. = 18, 43 p = 0.015	Southern Branch: Cu↑ Fe↑ Elizabeth River Mainstem: Fe↑
	End (Day 10)	Wilk's = 0.04 F = 3.70 d.f. = 21, 38 p = <0.001	Southern Branch: Cu↑ Fe↑ Elizabeth River Mainstem: Fe↓ Thimble Shoal: Fe↓

* Significant degrees of freedom not available for four treatment multivariate comparisons on a single day.

Turbidites in all treatments increased following the dump and decreased throughout the next six days of the experiment (Fig. A14). Likewise, SS and VNR values increased following the dump, but concentrations returned to pre-dump levels or lower within 48 hours (Figs. A15, A16). The turbidities, SS and VNR values of the fine sediments of the "controls" were somewhat higher during this period than those of the experimental treatments. All three of these parameters declined throughout the remainder of the experiment. This decline was possibly associated with the end of a phytoplankton bloom observed in all barrels (see below).

The nutrients in the seawater were much higher in microcosm #2 than in microcosm #1. Nitrates and nitrites were detectable throughout the experiment, but did not appear to be greatly affected by the simulated disposal event (Figs. A18, A19). Nitrites tended to increase towards the end of the experiment. Ammonia levels, which were initially quite low, appeared to be elevated by the dump, especially in the tanks containing sediments from the Elizabeth River (SB, EMS) (Fig. A19). The NH_3 levels then appeared to go through a series of cycles. The TKN levels did not appear to be affected by the introduction of any of the experimental sediments (Fig. A20). The TKN values dropped between days 3 and 4 and then cycled until the end of the experiment. Orthophosphates which were quite high immediately prior to the dump appeared to be slightly depressed by the simulated disposal operations (Fig. A21). The values tended to rise throughout the remainder of the experiment. The TP concentrations were initially quite high and did not appear to be affected by the dump (Fig. A22). However, as with TKN, the values dropped rapidly between

days 3 and 4. Following this drop, the TP values were essentially equal to the OPO_4 concentrations.

Chlorophyll a values were very high during the acclimation period, indicating bloom conditions (Fig. A23). During the days following the dump, the chlorophyll a values declined in all of the barrels. Chlorophyll b was quite low throughout the experiment except on day 2 when there was a peak in all tanks (Fig A24). A similar pattern was observed for chlorophyll c and phaeophytin (Figs. A25, A26).

The DO concentrations were moderately high during the acclimation period, but did not appear to be affected immediately following the dump (Fig. A27). However, the DO levels did drop, particularly on the days (5 and 6) following the phytoplankton bloom. Values never dropped below 6 ppm. The pH values were very high at the beginning of the experiment, but declined slightly as the autotrophic activities in the barrels decreased (Fig. A28).

The MANCOVA analysis of microcosm #2 water quality data indicated a highly significant difference between the treatments (Table 1). The univariate tests indicated that the SB and EMS treatments had higher levels of nitrites and nitrates than the TS or control treatments. The SB barrels had lower concentrations of chlorophyll a, DO and pH and higher levels of OPO_4 than the controls. On the other hand, the EMS treatment had higher levels of chlorophyll a, DO and pH and lower levels of OPO_4 than the controls.

The water samples were analyzed for metals immediately before the dump, four hours after the dump, and at the end of the

experiment (Table 2). No significant differences were observed between the treatments prior to the dumps in either of the experiments. Most metals except Fe and Cu decreased in all barrels following the dump. After the dump, the Fe concentrations were significantly higher than the controls in the SB, EMS and HR treatments. The Cu values also were elevated above the controls in the SB treatment.

Zooplankton

Nearly 40 species of zooplankton were observed in the HR treatment. There were no significant differences between the major zooplankton communities for microcosm #1 either before the dump or at the end of the experiment (Appendix B).

Similar results were reported in microcosm #2 for the zooplankton community structure studies (Appendix C). No significant differences were observed between the zooplankton communities exposed to the various treatments. Over 20 taxa of zooplankton were observed in the barrels at the end of the experiments.

Benthos

Nearly 70 benthic species were observed in both the control and HR barrels in microcosm #1. There was a significant difference between the benthic communities exposed to the four treatments (Appendix D). The univariate tests indicated which treatment-taxa combinations were significantly different from the abundance values observed for the "control-adjacent" communities. The HR dump communities had lower levels of the annelids <u>Eteone</u>

TABLE 2. Metal concentrations (mg/l) in water. Standard errors are in parentheses.

Experiment	Period	Treatment	Cd	Cr	Cu	Mn	Ni	Zn	Fe	Pb	Hg
			Metal								
1. Microcosm #1	Before dump (Day 0)	Control	BDL	BDL	0.003 (0.003)	BDL	BDL	0.013 (0.001)	0.030 (0.00)	BDL	BDL
		HR	BDL	BDL	BDL	BDL	BDL	0.017 (0.015)	0.030 (0.008)	BDL	BDL
	After dump (Day 0)	Control	0.0002 (0.0001)	BDL	BDL	BDL	BDL	0.012 (0.0005)	0.089 (0.019)	BDL	BDL
		HR	0.0002 (0.0001)	BDL	BDL	BDL	BDL	0.015 (0.0005)	0.387 (0.010)	BDL	BDL
	End (Day 10)	Control	BDL	BDL	0.021 (0.002)	BDL	BDL	0.011 (0.0005)	0.030 (0.004)	BDL	BDL
		HR	BDL	BDL	0.013 (0.002)	BDL	BDL	0.007 (0.0007)	0.045 (0.005)	BDL	BDL
2. Microcosm #2	Before dump (Day 0)	Control	0.005 (0.002)	BDL	0.015 (0.007)	BDL	0.031 (0.012)	0.022 (0.008)	0.085 (0.007)	0.020 (0.003)	0.0017 (0.0004)
		SB	0.002 (0.002)	BDL	0.019 (0.002)	BDL	0.030 (0.012)	0.041 (0.011)	0.043 (0.018)	0.026 (0.002)	0.0066 (0.0016)
		EMS	0.001 (0.0005)	BDL	0.013 (0.001)	BDL	0.028 (0.014)	0.022 (0.007)	0.058 (0.024)	0.022 (0.002)	0.0013 (0.0004)
		TS	0.002 (0.001)	BDL	0.016 (0.001)	BDL	0.023 (0.002)	0.025 (0.008)	0.085 (0.034)	0.020 (0.002)	0.0011 (0.0004)
	After dump (Day 0)	Control	0.0005 (0.0005)	BDL	0.009 (0.0003)	BDL	0.0003 (0.0003)	0.014 (0.0031)	0.421 (0.0439)	BDL	0.0002 (0.0001)
		SB	0.0002 (0.0002)	BDL	0.011 (0.0003)	BDL	0.0007 (0.0007)	0.017 (0.0014)	0.874 (0.03)	BDL	0.0006 (0.0001)
		EMS	0.0002 (0.0002)	BDL	0.009 (0.0006)	BDL	0.0003 (0.0003)	0.013 (0.001)	0.701 (0.0467)	BDL	0.0006 (0.0002)
		TS	BDL	BDL	0.010 (0.0005)	BDL	BDL	0.014 (0.0022)	0.799 (0.029)	BDL	0.0004 (0.0001)
	End (Day 10)	Control	0.0002 (0.0002)	BDL	0.006 (0.0003)	BDL	0.0002 (0.0002)	0.015 (0.006)	0.046 (0.0087)	BDL	0.0004 (0.0001)
		SB	0.0004 (0.0002)	BDL	0.008 (0.0007)	BDL	0.0006 (0.0005)	0.018 (0.0081)	0.098 (0.0197)	BDL	0.0002 (0.00005)
		EMS	BDL	BDL	0.007 (0.0003)	BDL	BDL	0.008 (0.0032)	0.025 (0.0055)	BDL	0.0002 (0.00006)
		TS	0.0002 (0.0002)	BDL	0.006 (0.0002)	BDL	0.0038 (0.0033)	0.007 (0.0036)	0.028 (0.0067)	0.002 (0.0018)	0.0003 (0.0002)

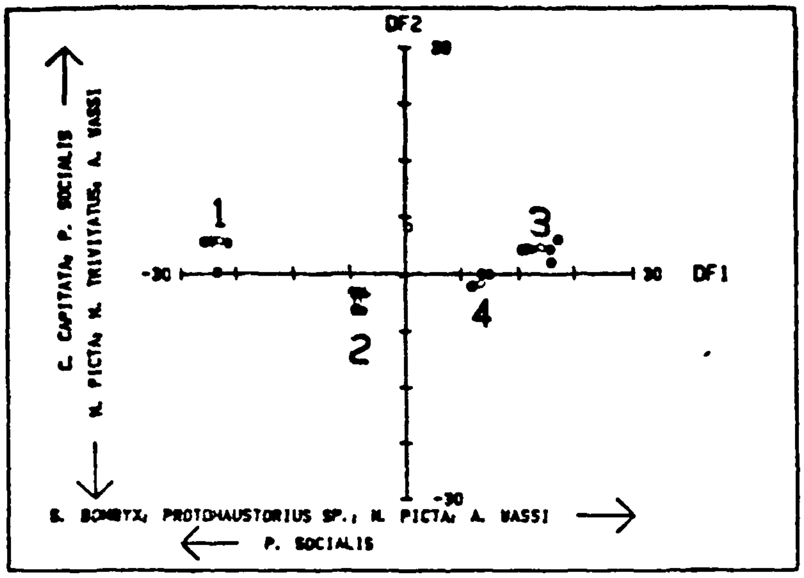
lactea, Protodorvillea kefersteini, Paraprionospio pinnata, Polygordius spp.; nemerteans; and the amphipod Trichophoxus floridana. On the other hand, the HR adjacent communities had elevated abundances of Brania wellfleetensis, Eteone lactea and Trichophoxus floridana. The control dump communities also exhibited elevated levels of certain species: Eteone lactea, Polygordius spp., nemerteans and Trichophoxus floridana.

Over 55 taxa were observed in the experimental chambers of microcosm #2 (Appendix E). The SB and EMS treatments produced significant changes in benthic community structure when compared to the controls, while the TS treatment did not. The SB "dump" treatment significantly lowered the abundance of the annelids Nephtys picta and Sthenelais boa; the bivalves Ensis directus, Tellina agilis and Spisola solidissima; and the amphipods Protohaustorius spp. The introduction of even control sediments appeared to cause a decrease in N. picta densities. The SB-adjacent chambers had significantly elevated densities of N. picta. The EMS-dump treatment produced reduced levels of N. picta and Spiophanes bombyx, but elevated levels of Capitella capitata and Polydora socialis.

Supplementary MANOVA models compared the benthos of all dump treatments together, as well as the communities of all adjacent treatments. None of the adjacent communities proved to be significantly different from the controls. However, the dump treatments were shown to be significantly different. This was primarily due to the previously discussed effects of the SB-dump and the EMS-dump treatment, as well as elevated levels of Spiophanes bombyx, Nephtys picta and Aricidea wassi in the TS-dump chambers.

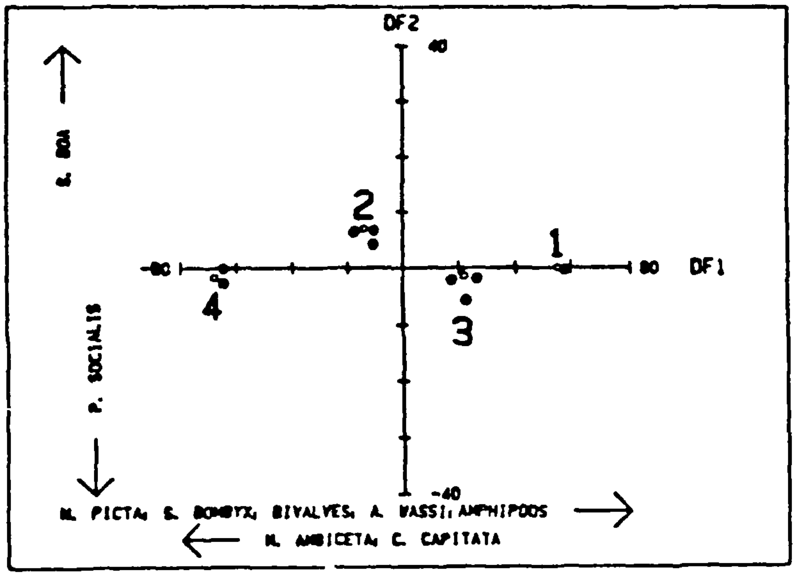
In order to visually present the differences in benthic community structure associated with the eight treatments, a series of discriminant analyses were run on data sets producing significant MANOVA models. Although the discriminant analysis procedure is often too sensitive to represent a valid statistical test, it does provide a very effective means of data presentation (Alden, 1984). The dependent variables can be related to the discriminant functions through a Pearson's correlation analysis of the benthic abundance data with the discriminant function scores. Therefore, the axes can be named (in descending order of significant correlations) so that the relative patterns of the groups can be plotted (Alden et al., 1981). Figure 3 presents the results of the three discriminant models: the EMS dump and adjacent communities compared to the control dump and adjacent communities; the SB dump and adjacent with the two control communities; and all four dump communities (SB, EMS, TS and control). The TS versus controls discriminant model and the model comparing the four adjacent communities were not run because these comparisons were not shown to have significant differences in the definitive MANOVA tests.

The major separation among the EMS versus control communities appears to be due to a somewhat greater abundance of certain taxa in the control groups: **Spiophones bombyx**, **Protohaustorus** amphipods, **Nephtys picta** and **Aricidea wassi** (Fig. 3a). The separation between the dump and adjacent treatments of both sediment types was due to higher numbers of **N. picta**, **Nassarius trivittatus** and **A. wassi** in the adjacent treatments relative to

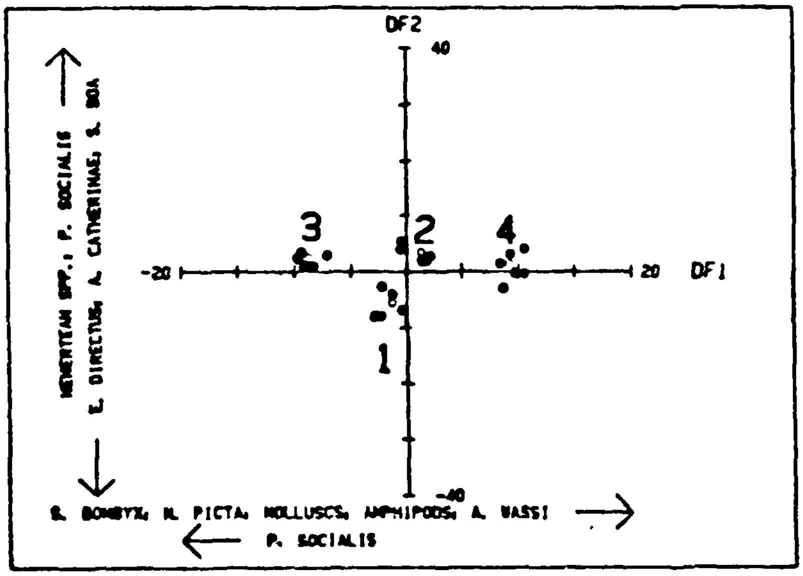


o = CENTROID

A
1 = EMS DUMP
2 = EMS ADJ.
3 = CONTROL DUMP
4 = CONTROL ADJ.



B
1 = CONTROL ADJ.
2 = CONTROL DUMP
3 = SB ADJ.
4 = SB DUMP



C
1 = CONTROL DUMP
2 = EMS DUMP
3 = SB DUMP
4 = TS DUMP

the dump communities; and the higher densities of **Capitella capitata** and **Polydora socialis** in the dump treatments.

The SB dump was greatly separated from the adjacent treatments and the control dump communities due to lower numbers of **N. picta, S. bombyx**, bivalves (**Tellina agilis, Ensis directus** and **Spisula solidissima**), and **Protohaustorius** amphipods (Fig. 3b). The SB dump did have somewhat higher values of three annelids: **Mediomastus ambiseta, C. capitata** and **P. socialis**.

When all four dump communities are compared, the SB group has the lowest densities of taxa correlated with DF1 (e.g. **S. bombyx, N. picta, A. wassi**, the bivalves, and the amphipods) and the TS samples had the highest (Fig. 3c). The EMS dump and the control dump communities were very similar along DF1. The differences between these two groups were slight and tended to be due to somewhat higher concentrations of **E. directus, Aricidea catherinae** and **Sthenelais boa** in the controls.

Body Burdens

During microcosm #1, the benthic infaunal polychaetes were analyzed for heavy metals (Table 3). No significant treatment effects, either due to sediment type or proximity, were observed in the metal concentrations of these organisms.

The **Mercenaria mercenaria** populations placed in dump trays during microcosm #1 were analyzed for chlorinated hydrocarbons (CHC's) (Table 4). The multivariate comparison of the two treatments was only marginally significant ($p=0.059$), but the univariate tests for Heptachlor epoxide and p,p-DDE were significantly higher ($\alpha=0.05$) in the HR treatments. The mean

TABLE 3. Metal concentration (μg/g) in infaunal annelids from microcosm #1. Standard errors are in parentheses.

	Treatment			
	Control		Hampton Roads	
Metal	Dump	Adjacent	Dump	Adjacent
Cadmium (Cd)	0.19 (0.07)	0.68 (0.46)	0.09 (0.03)	0.43 (0.18)
Copper (Cu)	162.20 (42.16)	286.20* (99.24)	62.33 (17.35)	203.04* (66.82)
Manganese (Mn)	11.83 (3.26)	17.17 (5.25)	12.32 (7.69)	20.11 (9.02)
Nickel (Ni)	32.30 (16.73)	160.90 (153.50)	30.00 (18.63)	87.75 (61.06)
Zinc (Zn)	356.67 (180.90)	679.88 (348.15)	353.62 (258.77)	726.44 (285.76)
Iron (Fe)	1,347.39 (601.55)	813.54 (177.90)	406.88 (103.53)	597.16 (187.48)
Lead (Pb)	8.36 (3.11)	11.22 (8.09)	4.97 (3.43)	19.71 (9.48)

Results of MANOVA tests of sediment treatment and proximity effects on body burdens of metals in annelids:

Sediment (Control vs. Hampton Roads)	Proximity (Adjacent vs. Dump)	Sediment x Proximity
Wilk's = 0.67	Wilk's = 0.65	Wilk's = 0.61
F = 0.76	F = 0.83	F = 0.99
d.f. = 7, 11	d.f. = 7, 11	d.f. = 7, 11
p = 0.63	p = 0.58	p = 0.49

* Univariate tests indicated that adjacent annelids had significantly higher concentrations than did those exposed to dump conditions.

TABLE 4. Chlorinated hydrocarbon concentrations (ng/g) in *Mercenaria mercenaria*. Standard errors are in parentheses.

CHC	Detection Levels (ng/g)	Treatment: Hampton Roads Sediment	Treatment: Control
α-BHC	7	14 (2)	13 (1)
Lindane	7	7 (0.6)	BDL
Aldrin	7	23 (8)	12 (2)
Heptachlor epoxide	7	20† (3)	9 (2)
Kepone	98	BDL	BDL
o,p-DDT	12	42 (17)	38 (20)
p,p-DDD	12	BDL	BDL
p,p-DDT	12	13 (7)	BDL
p,p-DDE	12	27† (4)	15 (3)
PCB's	60	BDL	BDL

Results of MANOVA tests of treatment effects on body burdens of pesticides:

Wilk's = 0.15
F = 3.80
d.f. = 9, 6
p = 0.059

† = Significant difference (α=0.05) in univariate comparisons.

values of other CHC's appeared to be somewhat higher in the clams exposed to HR sediments, but all concentrations were very near to detection limits, so the variation between replicates was high. However, the fact that all values were either very low (low ppb) or not detectable indicates that CHC uptake from HR sediments is of little ecological concern.

During the microcosm #2 experiments, **Mercenaria mercenaria** populations exposed to dump conditions were analyzed for heavy metals (Table 5). None of the exposure conditions produced body burdens of metals that were significantly different from those of the controls.

The clams from the microcosm #2 experiment were analyzed for PNAH's. The decision to analyze for PNAH's rather than CHC's was based upon the findings of studies conducted between the two microcosms (Alden and Hall, 1984; Alden et al., 1985a,b) which indicated that the former class of toxins were of far greater ecological concern to the region than the latter. The results of the microcosm #1 experiment also indicated that the initial concerns over significant Kepone bioaccumulation in organisms exposed to sediments from the Hampton Roads area were unfounded. The results of the PNAH analyses are presented in Table 6. Only the clams exposed to SB sediments contained PNAH's above detection limits: fluoranthene (Fl), pyrene (Pyre), chrysene (Ch), and benzo(k)fluoranthene (B(k)Fl). Of these PNAH's, Fl and Pyre were the two which exhibited mean concentrations that had 95% confidence limits that did not contain zero (the default value used for BDL measurements in the statistical analyses). Therefore

these PNAH's could be considered to be significantly elevated in the SB clams.

TABLE 5. Metal concentrations (μg/g) in *Mercenaria mercenaria*. Standard errors are in parentheses.

	Treatment			
Metal	Control	Southern Branch of Elizabeth River	Mainstem of Elizabeth River	Thimble Shoal Channel
Cadmium (Cd)	3.57 (1.00)	3.61 (0.58)	3.32 (0.50)	3.93 (0.99)
Copper (Cu)	12.67 (0.98)	14.89 (0.64)	14.45 (1.29)	15.24 (1.94)
Manganese (Mn)	11.31 (2.89)	10.33 (1.60)	10.07 (3.13)	23.30 (8.32)
Nickel (Ni)	18.81 (3.08)	21.91 (4.80)	23.36 (3.72)	17.23 (1.31)
Zinc (Zn)	153.16 (16.13)	172.75 (30.93)	150.12 (17.02)	142.59 (11.85)
Iron (Fe)	162.57 (48.94)	118.07 (24.82)	94.44 (4.85)	211.68 (22.64)

Results of MANOVA tests of treatment effects on body burdens of metals:

Wilk's = 0.19
F = 0.89
d.f. = 18, 20
p = 0.60

TABLE 6. PNAH's concentrations (ng/g) in Mercenaria mercenaria. Standard errors are in parentheses.

PNAH	Treatment: Control	Southern Branch of Elizabeth River	Mainstem of Elizabeth River	Thimble Shoal Channel
Naphthalene (N)	BDL	BDL	BDL	BDL
Acenaphthylene (Acy)	BDL	BDL	BDL	BDL
Acenaphthalene (Ace)	BDL	BDL	BDL	BDL
Fluorene (F)	BDL	BDL	BDL	BDL
Dibenzothiopene (DiB)	BDL	BDL	BDL	BDL
Phenanthrene (Ph)	BDL	BDL	BDL	BDL
Anthracene (A)	BDL	BDL	BDL	BDL
Fluoranthene (Fl)	BDL	765† (46)	BDL	BDL
Pyrene (Pyre)	BDL	327† (38)	BDL	BDL
Benzo(a)Anthracene (B(a)A)	BDL	BDL	BDL	BDL
Chrysene (Ch)	BDL	190 (190)	BDL	BDL
Dibenzo(a,h)anthracene (DiB(a,h)A)	BDL	BDL	BDL	BDL
1,12-Benzoperylene (BP)	BDL	BDL	BDL	BDL
Benzo(a)pyrene (B(a)P)	BDL	BDL	BDL	BDL
Benzo(b)fluoranthene (B(b)Fl)	BDL	BDL	BDL	BDL
Benzo(k)fluoranthene (B(k)Fl)	BDL	293 (293)	BDL	BDL
Indeno(1,2,3-cd)pyrene (IP)	BDL	BDL	BDL	BDL

† = Significantly (α=0.05) higher than control levels based upon 95 confidence limits of non-zero means.

DISCUSSION

Water Quality Effects

The differences in water quality patterns observed in the two microcosm experiments is believed to be due to the initial conditions of the water in the barrels at the time of the experiments. Microcosm #1 was conducted during a mid-summer period (July) when nutrients and the associated phytoplankton activities are typically low in coastal waters in the vicinity of the NDS (Alden et al., 1984b; Alden and Butt, 1985). Therefore, the phytoplankton populations were quite low at the beginning of microcosm #1 (as evidenced by chlorophyll a concentrations), and probably limited by the low values of inorganic nutrients (e.g. NO_2, NO_3, OPO_4). The NH_3 and TKN values were already quite high, but these potential nutrients and TP, in particular, were elevated by the introduction of sediments in both treatments. A period of microbial activity apparently followed during which time ammonia was broken down by nitrification and the organic-bound nutrients (TP and TKN) were remineralized. Microbial respiration during this period (i.e. the 4-5 days following the dump) is believed to be responsible for the drop in oxygen and pH readings.

The nutrients released during this period of microbial activity stimulated a phytoplankton bloom, which apparently used the inorganic nutrients as they were being produced. Therefore, the organic nutrients (NH_3, TKN, TP) declined while the phytoplankton populations grew, without the intermediate inorganic nutrients building up to detectable concentrations. In other words, the increased flux of nutrients rather than the absolute

concentrations attained in the water appeared to have stimulated the bloom in a previously nutrient-limited system. It is suspected that the organic materials and the suspended solid load introduced by the sediments during the dump stimulated the microbial remineralization process that initiated this sequence. However, differences between the two treatments were minimal and the overall water quality patterns in all barrels were nearly identical.

The initial conditions in microcosm #2 were quite different. The experiments were conducted during the spring (late May, early June) when phytoplankton populations (chlorophyll a) were in a bloom condition and the nutrients appeared to be quite high. Such spring blooms are common in coastal ecosystems. The dump increased turbidities, suspended solids, and VNR levels in all barrels. However, as with the microcosm #1 experiments, these changes were transient, lasting less than 48 hours.

During the days following the dump, the chlorophyll a in all barrels declined rapidly. On day 2 following the dump, chlorophylls b and c suddenly peaked. Although it cannot be established with certainty that this event was related to the end of bloom conditions, the apparent concentrations of these chlorophylls may represent interferences associated with the formation of various phaeo-pigments by senescent phytoplankton populations. Phaeophytin a also peaked at this time, lending evidence to this speculation. All the water quality patterns following this period clearly indicated post-bloom conditions: lower turbidities and VNR concentrations; declining TP values;

increasing OPO_4 and NO_2 levels; and decreasing DO and pH readings.

The decline of bloom conditions in the chambers could be due to a natural cycle of events that would have occurred in the field. On the other hand, the "crash" could have been triggered by the lowered light conditions associated with post-dump turbidities. At bloom conditions, the phytoplankton may have rapidly declined due to the lower light conditions which may have been insufficient to maintain the growth of high-density populations. It is interesting to note that the EMS treatment conditions, which had a lower suspended solid load immediately following the dump, maintained higher chlorophyll a readings and primary production activities (as indicated by higher DO and pH readings) during the period of post-bloom decline. The SB treatment appeared to accelerate the decline of phytoplankton populations and the indicators of primary production (DO and pH). However, this effect can not be tied to the SS load alone since the fine control sediments produced a higher load with less of a response. A toxic effect appears to be indicated. Previous microcosm studies (Alden et al., 1981) showed a similar depression of phytoplankton populations (as indicated by chlorophyll a) exposed to sediments from the Southern Branch of the Elizabeth River. Elutriates of sediments from this region, as well as water taken directly from the River have shown relatively high concentrations of 1-4 ring aromatic compounds (Banks, 1977; Garbowsky, 1983; Alden and Hall, 1984) which would potentially be found in the water column of the SB treatments. Such compounds are known to be toxic to phytoplankton populations.

The water quality patterns observed in the two microcosms may or may not have an ecological analog for real disposal operations. The tests were static, whereas the dynamic waters of open ocean disposal sites such as NDS tend to have great capacities for dilution and dissipation. Therefore, occasional disposal operations by hopper barges would be expected to have little effect on the water quality of the region. More intensive operations for longer periods of time, such as may be expected during new harbor deepening projects, would be expected to have a greater potential for effects. Fortunately, the results of microcosms indicate that the potential impacts if they did occur, would be subtle and may not be adverse: the tendency for increasing phytoplankton populations during periods of low productivity and decreasing the populations during bloom conditions. Elevated turbidity and suspended solid loads would be expected to be localized and transient. The only real ecological concern would be for the apparent toxicity of the SB sediments for the phytoplankton communities.

The metals in the water study indicated very subtle changes due to the simulated dumps. In microcosm #1, iron was observed to be elevated in the HR treatment tanks following the dump. This trend was not too suprising since the SS load of the finer HR sediments contained a higher iron content than the NDS sediments (Alden _et al_., 1981). By the end of the experiment, iron levels in the HR barrels had returned to control levels. In fact, zinc levels in the HR barrels were somewhat below those of the controls or the initial pre-dump concentrations, possibly due to scavenging

by the SS load and/or by co-precipitation with iron.

The microcosm #2 metals in the water study produced similar results; iron values increased in the water of the two Elizabeth River treatments (EMS and SB) immediately following the dump. However, the concentrations of all other metals tended to decrease following the dump in all barrels. The scavenging of the metals by the introduced sediments is a possible explanation. Iron remained elevated in the SB barrels (relative to the controls) at the end of the experiment, but the concentrations were very close to the pre-dump values.

The effects of the simulated dumps on the metals in the water column appears to be of minimal ecological importance. Iron has an extremely low toxicity, even in the dissolved form. Furthermore, it is believed that most of the iron was associated with the SS load and not very biologically available. Perhaps the greatest effect noted in both microcosms is that metals actually decreased following the dump and remained lower at the end of the experiments. This phenomenom has been noted in previous microcosm studies (Alden et al., 1981). Therefore, the effect of ocean disposal might be to actually lower the water column concentrations of certain metals.

Biological Effects

Zooplankton populations have been shown to be sensitive to exposure of the suspended solid fraction of sediments from the Southern Branch of the Elizabeth River, either in single species bioassays (Alden and Crouch, 1984) or in multiple species microcosms (Alden et al., 1981). However, the dredging of the

collection sites in the Southern Branch in the fall of 1981 decreased the degree of contamination (Alden and Hall, 1984) and the toxicity of the sediments (Alden and Young, 1984; Alden et al., 1984a; Alden et al 1985b). Although these studies have indicated that the contamination/toxicity of the sediments of this region has begun to return since dredging, the zooplankton exposed to the relatively dilute SS fraction in microcosms conducted approximately 18 months after dredging showed no significant effects on community structure.

Likewise, the zooplankton communities exposed to EMS, TS or HR sediments were not significantly affected. The estimated 96-hour LC50 value for the copeopod **Acartia tonsa** exposed to the SS load of fine, uncontaminated sediments is approximately 75 mg/l (Alden and Crouch, 1984). Since the suspended solids in all of the barrels never approached this level even immediately following the dump, no mortality due to the physical effects of the materials would be expected. Since no relative effects were seen between treatments, it is assumed that the toxicity of all sediments tested is negligible for the organisms of the water column.

As with previous microcosm studies (Alden et al., 1981), the effects of the sediments on the benthic communities was significant but subtle. The majority of taxa not in trace densities appeared in all treatments, so the responses of the benthos to various sediment types consisted of differences in relative abundance. Community structure changes generally consisted of decreased densities of what are considered clean-sand faunal

assemblages in the dump trays of certain sediments.

The most significant responses were observed in the SB dump treatments. Bivalves, amphipods and certain sand-dwelling worms were all observed to be in relatively lower densities in this treatment. Survival of the bivalves **Ensis directus, Tellina agilis**, and **Spisula solidissima**; the amphipods **Protohaustorius spp.**; and the annelids **Sthenelais boa** and **Nephtys picta** appeared to be lower in the SB dump than in the other treatments. All of these taxa are typical of clean, sandy habitats. **Nephtys picta** is a strong swimmer (Dr. D.M. Dauer, personal communication) which may have moved out of the dump trays, through the microcosms and into the adjacent trays. Such an active substrate selection was observed for mobile taxa in previous microcosms (Alden et al., 1981). This species displayed a similar pattern in the control-dump treatment with clean fine sediments, so at least part of the effect may have been an active preference for a coarser grain substrate. The remaining taxa did not display significant reductions in the fine sediment control-dump, so it is believed that their response is due to the toxicity of the SB sediments. Thus, the post-dredging return of toxicity observed in bioassays (Alden and Young, 1984) has also been observed in these microcosms. No benthic community structure responses were observed nine months after dredging (Alden et al., 1985a), but the results of the present study indicated clear changes to be associated with exposure to sediments collected 18 months after the dredge operations.

The effects of the EMS sediments were less significant and far more subtle. In fact, the community structure changes

observed to be associated with the EMS-dump treatment were similar to those seen for the control-dump treatment. Therefore, much of the observed changes are believed to be due to particle size effects (e.g. fine sediment taxa such as **Capitella capitata**, replacing sand-loving taxa such as **Nephtys picta** or **Spiophones bombyx**) rather than toxic effects. The TS treatments produced no significant adverse effects. In fact, the exposed communities had somewhat higher densities of taxa affected by the fine sediments (e.g. bivalves, amphipods, sand-loving worms) than did in the other dump treatments. The TS sediments from the Chesapeake Bay are coarser than the other test sediments and more like those of NDS. The TS sediments have also been shown to be relatively uncontaminated and non-toxic (Alden et al., 1981; Alden et al., 1985b). Therefore, the observed results are not surprising.

The effects of the HR sediment treatments were far more subtle than those observed for the other sediments. Despite the fact that the treatments had twice the number of replicates of those in microcosm #2 (and, therefore, higher degrees of freedom in a statistical sense), the community structure changes were barely significant at the $\alpha=0.05$ level. The dump conditions were associated with lower densities of certain sand-loving worms, nemerteans, and the sand-dwelling amphipod **Trichophoxus floridana**. However, some of these forms were observed to occur in greater abundances in the HR adjacent treatment, possibly as a result of active substrate selection between the treatment chambers (Alden et al., 1981). It is felt that much of the subtle changes are due to sediment size effects (i.e. fine HR sediments on sand-dwelling

NDS communities). However, since a fine sediment control was not used in this particular experiment (i.e. NDS sediments were used as reference materials), this trend cannot be demonstrated conclusively.

Perhaps the most significant finding of the benthic studies is that "adjacent" communities appear adversely to not be affected by the simulated disposal of the sediments tested. If any effect is noted, it is that the adjacent communities may be enriched by taxa leaving the dump conditions and actively seeking clean substrates. The communities tested are adapted to the highly dynamic coastal environments. Therefore, they appear to be able to tolerate the periodic impact of sediment loads. It is assumed that the dilution of any contaminants by the rather large volume of water passing over the dredged materials is responsible for the lack of significant toxic effects. Of course, the dilution fact or of the water, or for that matter of surrounding clean sediments, would be expected to be much greater in the field than in the microcosms.

The lack of adverse effects to the adjacent communities even under "worst case" static conditions is of ecological importance. It suggests that benthic communities living in the proximity of an open ocean disposal site (i.e. in habitats not directly receiving layers of dredged materials) would not be expected to be acutely impacted by disposal operations.

Body Burden Effects

The organisms exposed to test sediments in the microcosms did not exhibit any higher body burdens of heavy metals than did the

controls. In the first microcosm, neither sediment type nor proximity produced significant effects in the multivariate models. In fact, the mean concentrations of most metals were higher in the worms from the adjacent trays than in those directly exposed to the dumped sediments. This trend only proved to be statistically significant for copper. However, a similar pattern was observed in previous studies of the area (Alden et al. 1984c). Organisms exposed to fine, organic-rich sediments exhibited less accumulation of metals than those exposed to coarser materails, despite the fact that the latter had a much lower bulk concentration. The fine organic-rich sediments are believed to bind the metals more strongly than the sandier materials, thus lowering their bioavailability and potential for uptake. This trend appears to be the case with the fine HR sediments and may be the general explanation why so few studies on "contaminated" dredged materials have ever demonstrated significant bioaccumulation of metals (Neff et al., 1978; Engler, 1978; Peddicord and Hansen, 1983; Rubenstein et al., 1983).

The clams exposed in the second microcosm, likewise, did not exhibit significant bioaccumulation of metals following exposure to the test sediments. The levels were somewhat higher than those observed in the same species during static bioaccumulation experiments on sediments from the same regions (Alden et al., 1985b). However, this trend was to be expected. Clams exposed to more "natural" conditions of the micrcosms accumulated relatively higher levels of metals than those maintained in static bioassays (Alden et al., 1985a). The levels of metals in the clams were

either slightly lower than or equal to those observed in the previous microcosms (Alden et al., 1985a). The lack of significant accumulation of metals in the test clams of microcosm #2 is believed to be due to the same sediment-binding/ low bioavailability pattern. This speculation is supported by the fact that significant bioaccumulation of metals in clams was only observed when coarser dredged materials from certain areas of the Port were tested (Alden et al., 1985b). Even in the microcosm #2 experiment, the mean concentrations of most metals were somewhat higher in clams exposed to TS sediments, which were somewhat coarser and lower in organic content than the control and test sediments. The overall recurring pattern suggests that bioaccumulation of heavy metals should be negligible following ocean disposal of virtually all dredged materials from the Port.

During microcosm #1, the clams exposed to HR and control sediments were analyzed for CHC's. The uptake of Heptachlor epoxide and p,p-DDE, the breakdown product of DDT, were significantly higher in the clams exposed to control sediments. However, all of the CHC concentrations were extremely low (BDL or low ppb) and believed to be of very little environmental consequence. Similar conclusions were reached during the extensive bioaccumulation investigations of sediments from throughout the Port (Alden et al., 1985b).

The concentrations of most PNAH's in clams taken from the microcosm #2 tests were generally below detection limits. The exceptions were Fl, Pyre, Ch and B(k)Fl in clams exposed to SB sediments. Sediments from this region have been shown to be highly contaminated with PNAH's (Alden and Hall, 1984).

These same basic group of intermediate weight PNAH's were seen to have the greatest bioaccumulation potential in previous studies of the sediments of the region (Alden et al., 1985a,b). Alden et al. (1985a) discuss possible mechanisms for this particular bioaccumulation pattern.

The concentrations of the PNAH's in microcosm #2 clams to SB sediments taken 18 months after dredging were higher than the levels observed in clams from a microcosm experiment testing sediment from the same region only nine months after dredging (Alden et al., 1985a), so the bioaccumulation potential of the sediments appears to have increased as these contaminants re-invaded the channel during the post-dredging period. The bioaccumulation potential may, in fact, be still increasing with time since the re-invasion of the PNAH's into the sediments of the channel had not reached pre-dredging levels by the time all biological assessments were completed in 1983 (Alden and Hall, 1984). A further point should be made that **Mercenaria mercenaria** populations do not accumulate the PNAH's to as great a level as do **Palaeomonetes pugio** or **Mytilus edulis** in 10-day bioaccumulation experiments. As a result, the extent of the problem may be underestimated by 1-2 orders of magnitude (Alden et al., 1985b). It is the potential uptake of toxic/carcinogenic compounds by biota living in the vicinity of the NDS that make the SB sediments of greatest ecological concern. Therefore, the results of the microcosm study tend to confirm the recommendations from previous studies (Alden et al., 1981; Alden and Young, 1982; Alden and Hall, 1984; Alden and Young, 1984; Alden et al., 1984a; Alden et

al., 1985b) that the sediments from this particular region (in the vicinity of Stations M, N and O) not be considered for ocean disposal. The remaining sediments tested from throughout the Port appear to pose no problems in terms of bioaccumulation potential.

SUMMARY AND CONCLUSIONS

Microcosm experiments were conducted to test the relative quality of sediments taken from representative dredge project areas throughout the Port of Hampton Roads. The microcosms were designed to simulate certain field conditions so that natural assemblages of zooplankton and benthos could be exposed to potential dredged materials under more "realistic" conditions than can be achieved in the traditional 10-gallon tank static bioassays. The changes in community structure, water quality and body burdens of toxins were monitored in the microcosms following simulated "dumps" of various sediment types: materials taken from the Thimble Shoal access channels in the Chesapeake Bay (TS); the Hampton Roads Harbor (HR); the mainstem of the Elizabeth River (EMS); the Southern Branch of the Elizabeth River (SB); as well as control sediments.

The water quality patterns in the two microcosms following the dumps were quite different. The observed differences between the two experiments were apparently due to seasonally divergent initial conditions. When the seawater introduced into the microcosm barrels was taken from the field during a period of low primary production in mid-summer, the introduction of sediments, either control or experimental, stimulated microbial remineralization of nutrients. The increased flux of nutrients that were formerly limiting stimulated a phytoplankton bloom and all the associated changes in water quality. However, when bloom conditions existed at the beginning of the experiments, the post-dump turbidites in all treatments appeared to trigger a phytoplankton

population "crash" to more moderate densities. In both of these situations, almost all treatments produced similar overall results. Post-dump differences between treatments were transient, lasting less than 48 hours. The only treatment effect which would be of concern to the water quality of a disposal site was the apparent toxicity of the suspended solid load of SB sediments to the phytoplankton populations.

The effects of the simulated dumps on metals in the water column was minimal. Iron was the only metal to be elevated immediately after the dump of all sediment types. Most metal concentrations actually decreased after the dump, probably due to scavenging of metals by the transient post-dump S.S. load. The ecological impact of this pattern would be negligible.

None of the treatments produced a significant impact on the zooplankton communities. Previous microcosms and bioassays indicated that SB sediments were quite toxic to zooplankton, but that the toxicity disappeared following maintenance dredging of the region. Apparently, the toxicity of the sediments did not return within the 18-month post-dredging period to the point that the dilute exposure received by the zooplankton in the microcosm water column would prove lethal.

The benthic community studies indicated that most of the taxa observed survived all treatments. Therefore, the major effects were subtle shifts in community structure associated with differences in relative survival of certain taxa. Clean sand-loving annelids, bivalves, and amphipods were affected by the introduction of fine sediments, whether test or control. However,

the SB sediments produced significant, presumably toxic, effects that could not be attributed to particle size alone. None of the adjacent communities exhibited significant treatment effects, so benthic communities in the vicinity of a disposal site (i.e. not directly receiving the solid phase of sediments) would not be expected to be greatly impacted by any disposal operations.

The body burden studies indicated that biota exposed to all of the dredged materials did not significantly accumulate heavy metals. Likewise, the bioaccumulation potential of chlorinated hydrocarbons in all sediments were seen to be negligible. However, biota exposed to SB sediments did significantly accumulate certain 4- and 5-ring PNAH's which have been previously shown to have a large bioaccumulation potential. This accumulation pattern is of great ecological concern, particularly since the sediments in the region are apparently increasing in PNAH contamination following dredging operations. Moreover, the clams tested in the microcosms do not have as great an uptake rate for PNAH's as other taxa. Therefore, the full magnitude of the bioaccumulation potential of these organic toxins/carcinogens may not have been observed.

In summary, the microcosm experiments confirm the findings of previous studies indicating that most of the sediments from the Port of Hampton Roads would produce few ecological effects upon ocean disposal. However, the microcosms also confirmed the toxicity and bioaccumulation of potential sediments from the Southern Branch of the Elizabeth River. It is, therefore, recommended that sediments from this region not be considered for ocean disposal.

ACKNOWLEDGEMENTS

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We also extend our thanks to the other support people. They include: John Seibel, David Wade, Martha Norris for data analysis, and Joseph Winfield and Rita Hidalgo, the administrative staff.

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APPENDIX A

Water Quality Patterns
Microcosm #1 and #2

Mean values of each treatment indicated by letter (C=control, H=Hampton Roads, S=Southern Branch, E=Elizabeth River Mainstem, T=Thimble Shoal). Standard errors (±) are indicated by hyphens (n=12 for microcosm #1 and n=6 for microcosm #2).

Figure Al.

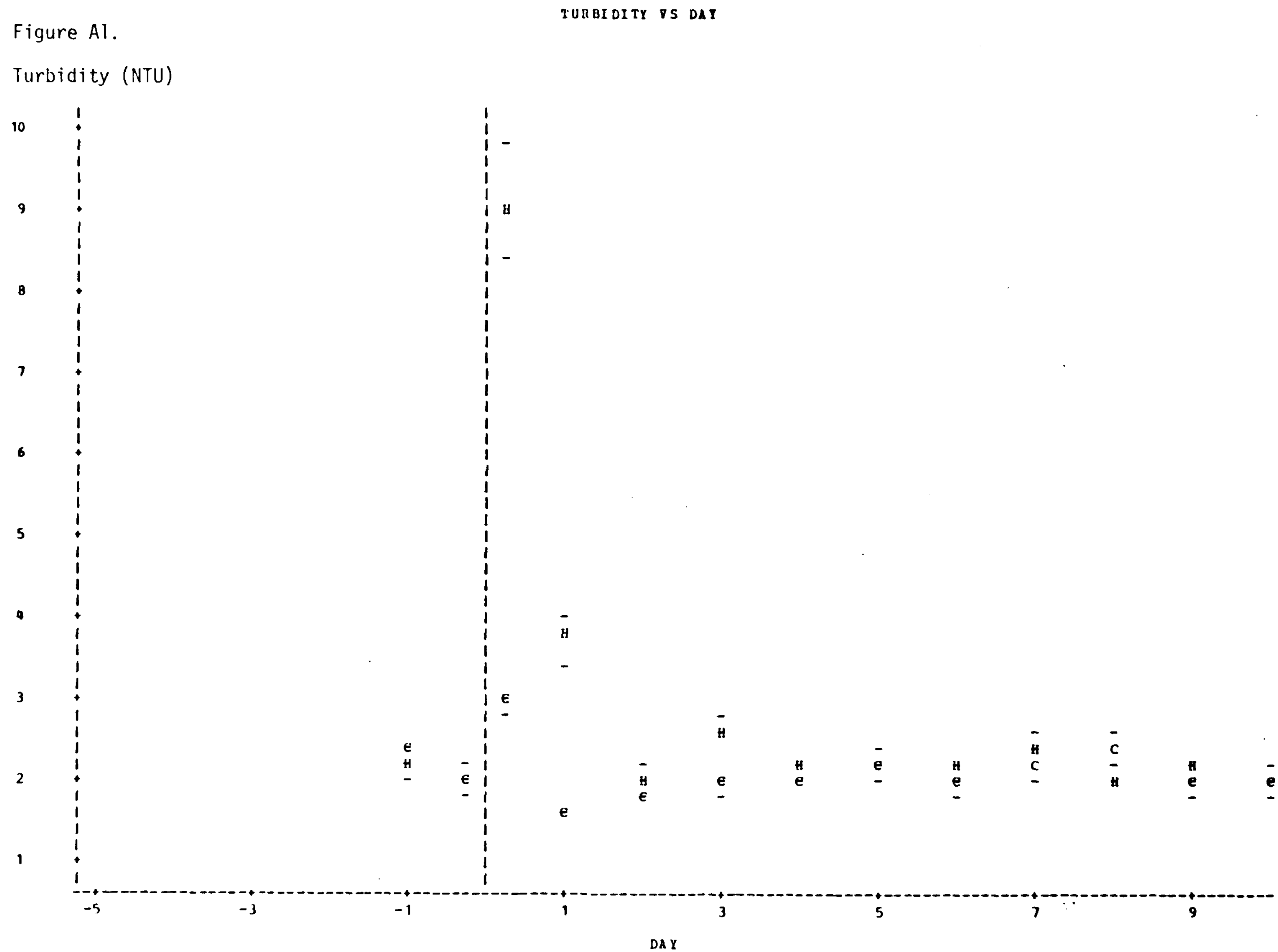
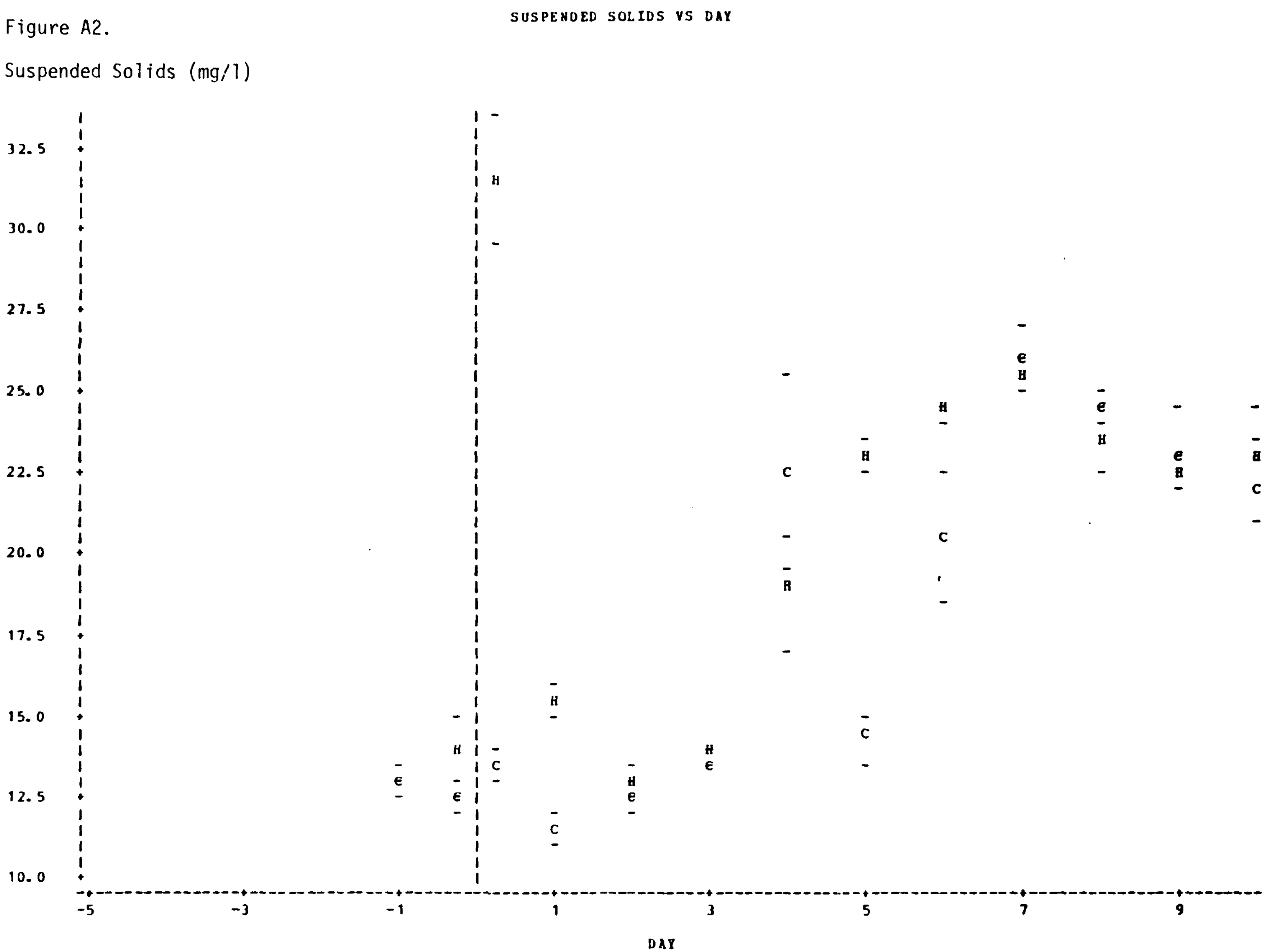


Figure A2.

Suspended Solids (mg/l)



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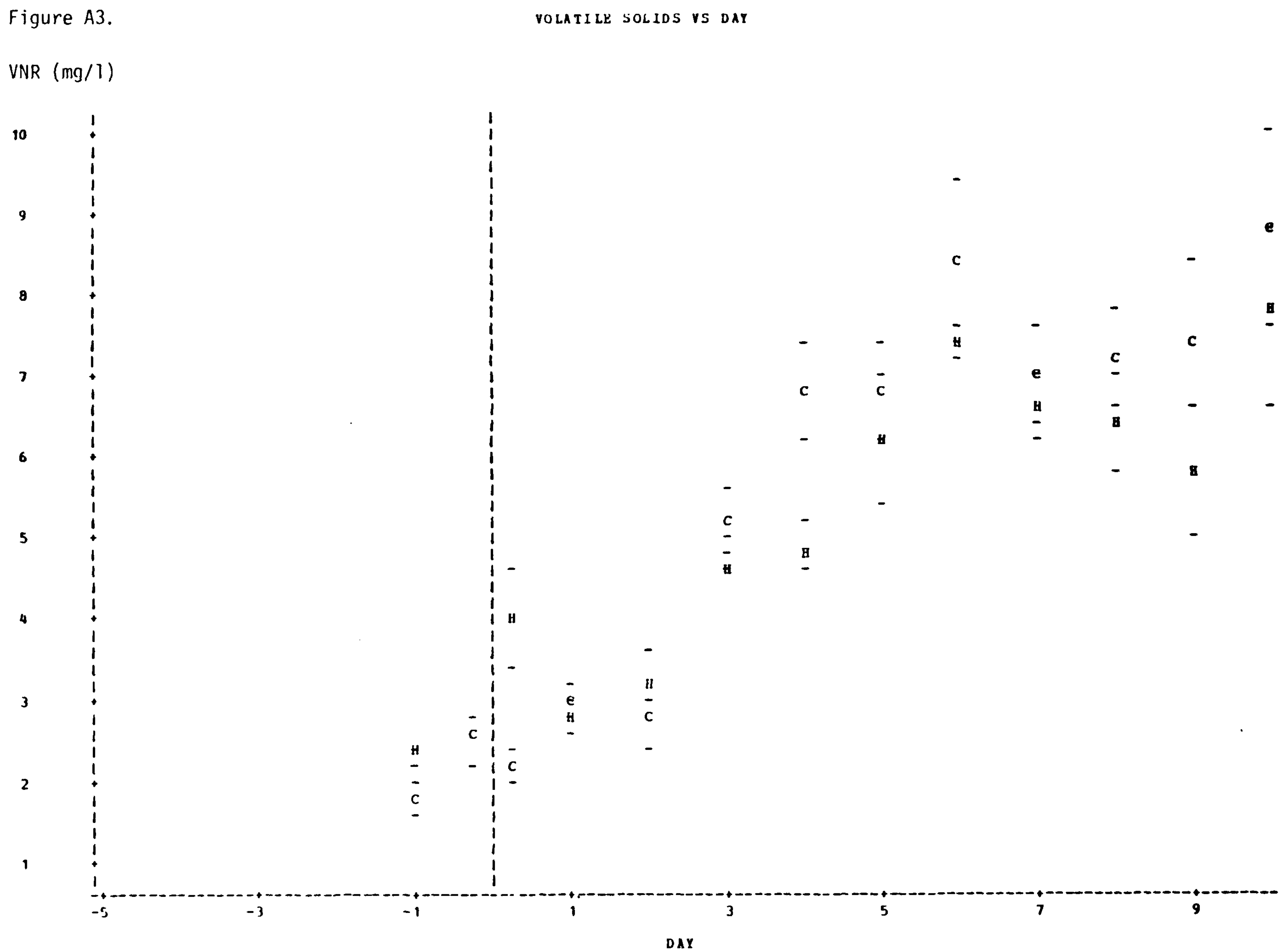

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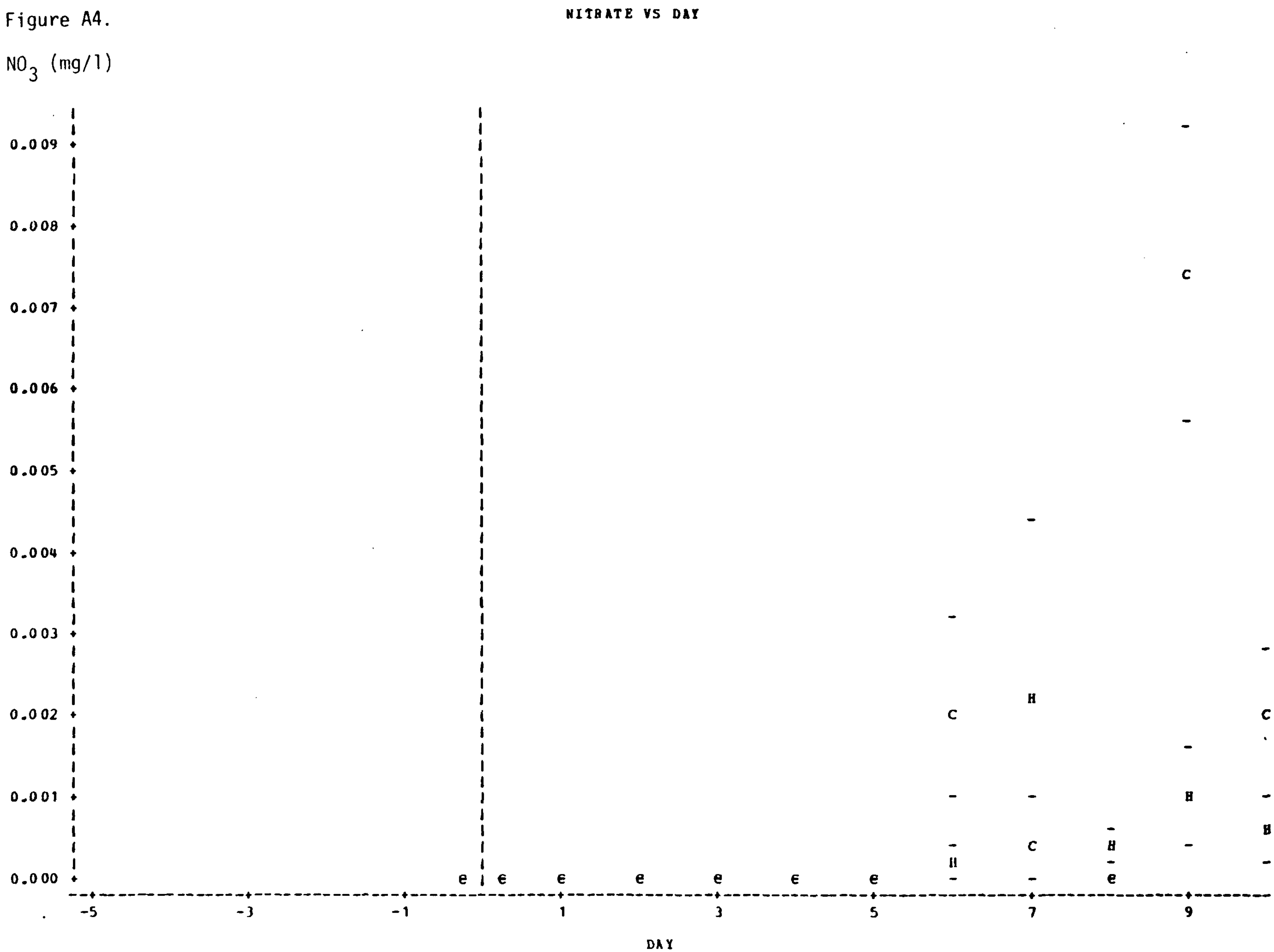

NITRATE VS DAY
NO3 (mg/l)
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
-5
-3
-1
1
3
5
7
9
DAY

Figure A5.

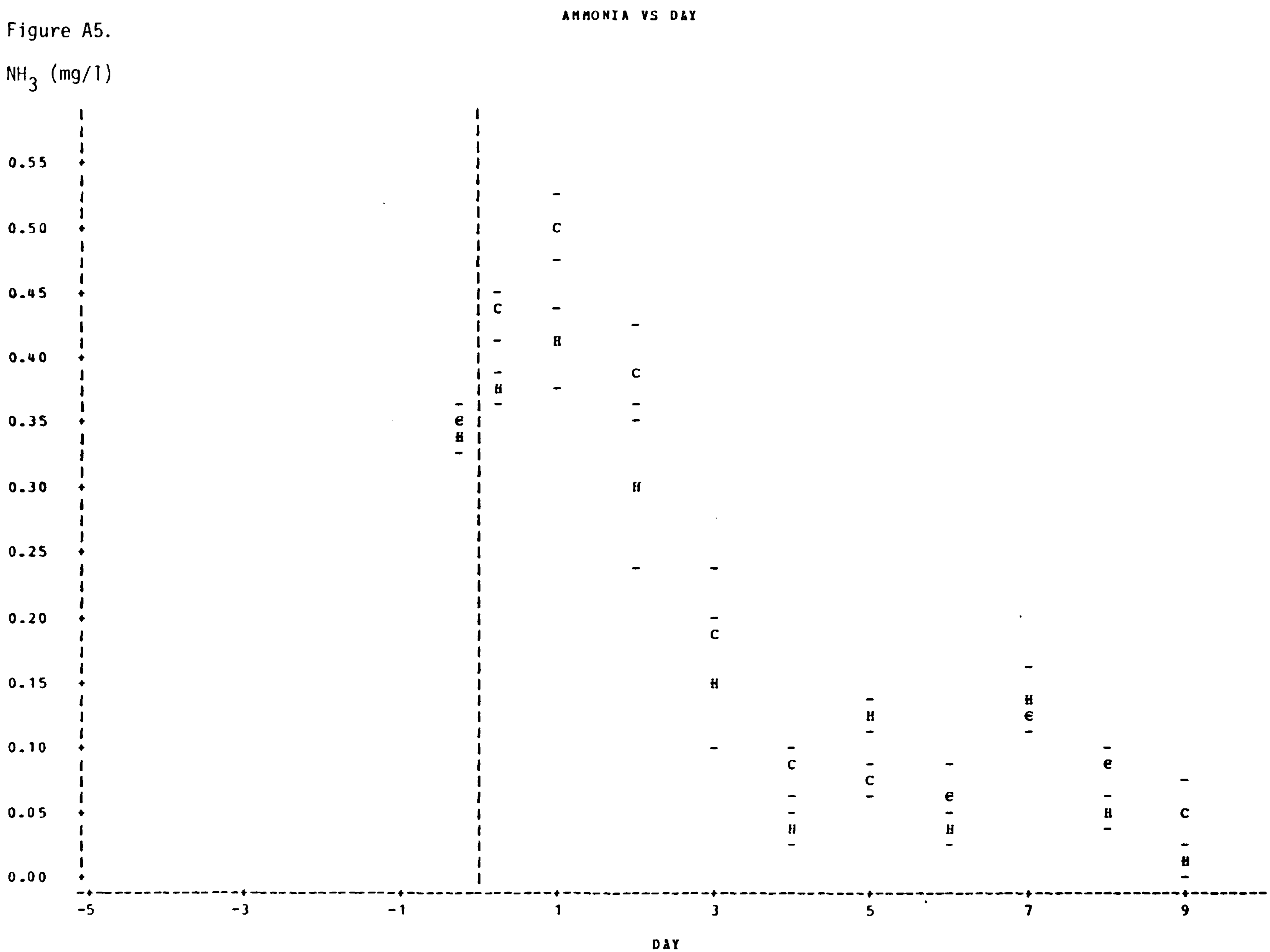
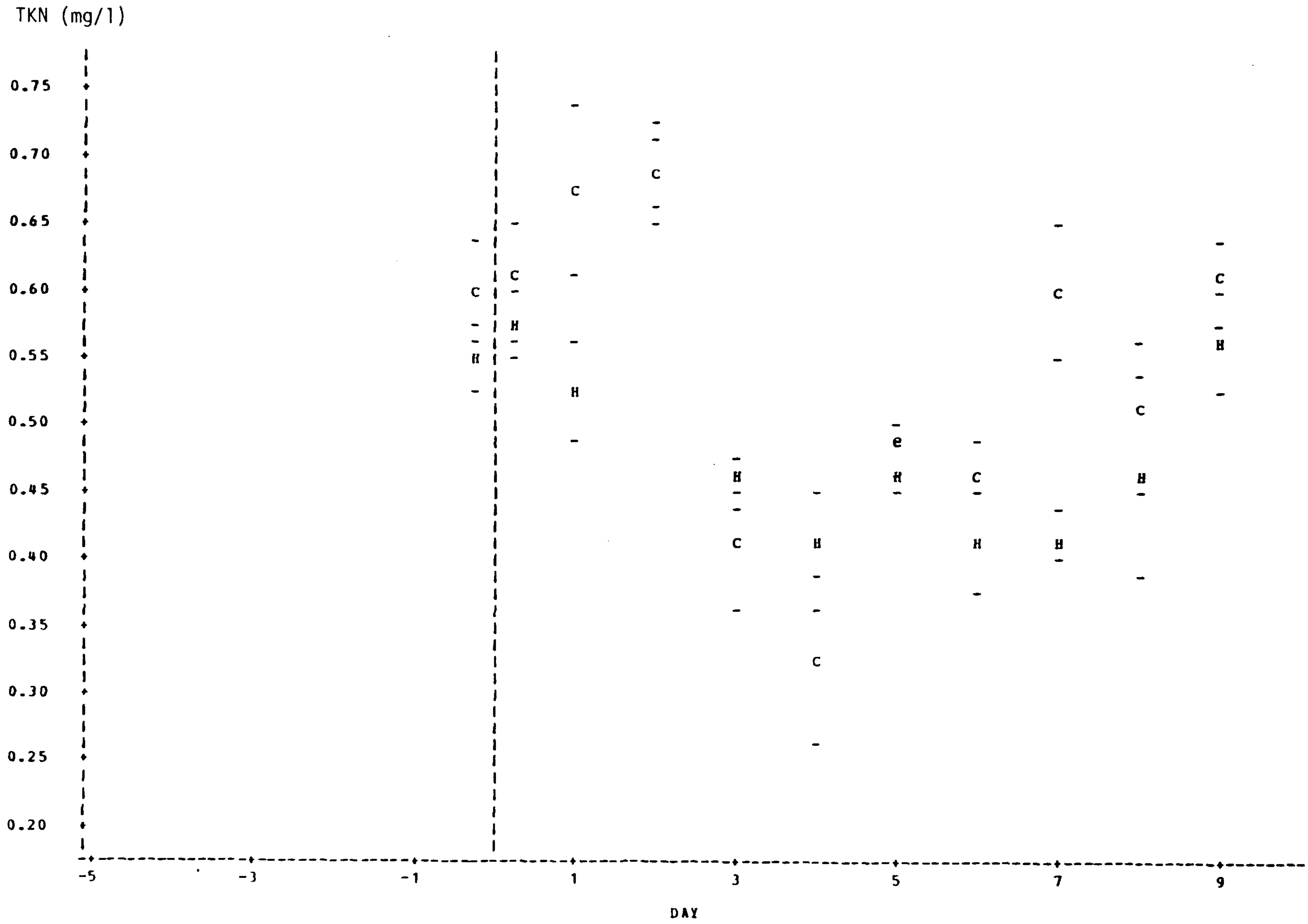

AMMONIA VS DAY
NH$_3$ (mg/l)
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-5
-3
-1
1
3
5
7
9
DAY

Figure A6.

TOTAL KJELDHAL NITROGEN VS DAY



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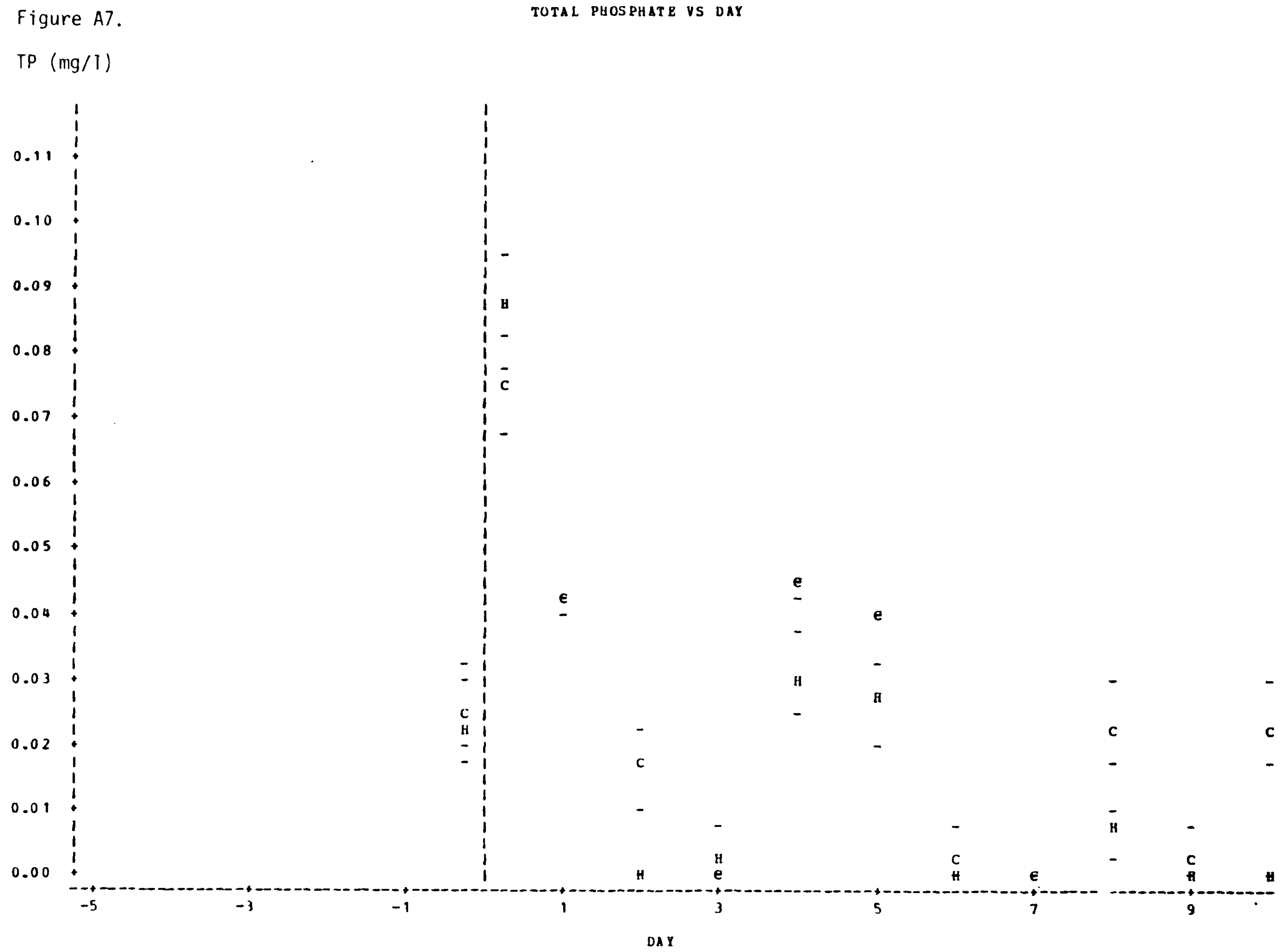

TOTAL PHOSPHATE VS DAY
TP (mg/l)
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-5
-3
-1
1
3
5
7
9
DAY

Figure A8.

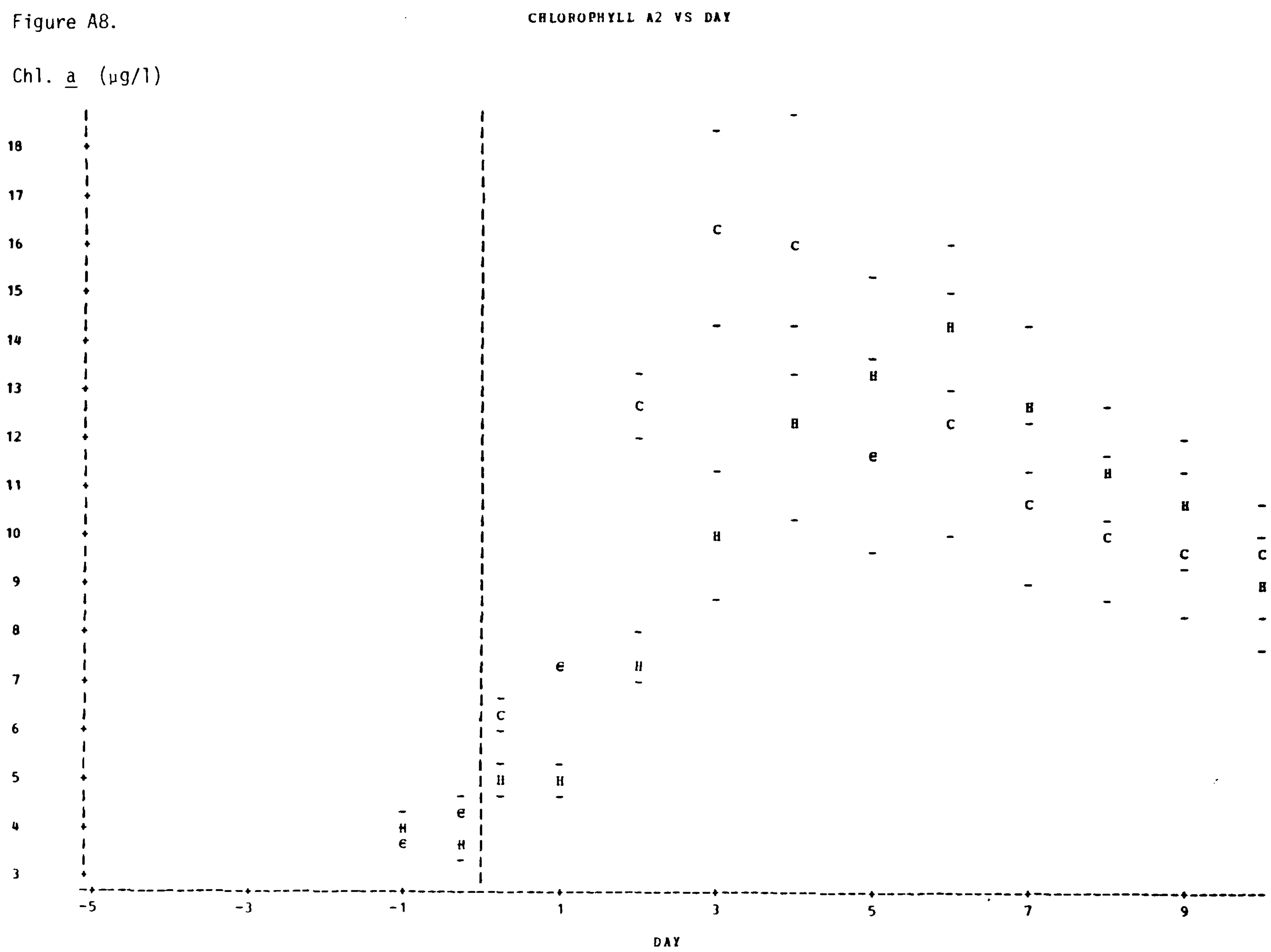

CHLOROPHYLL A2 VS DAY
Chl. a (µg/l)
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
-5
-3
-1
1
3
5
7
9
DAY

Figure A9.

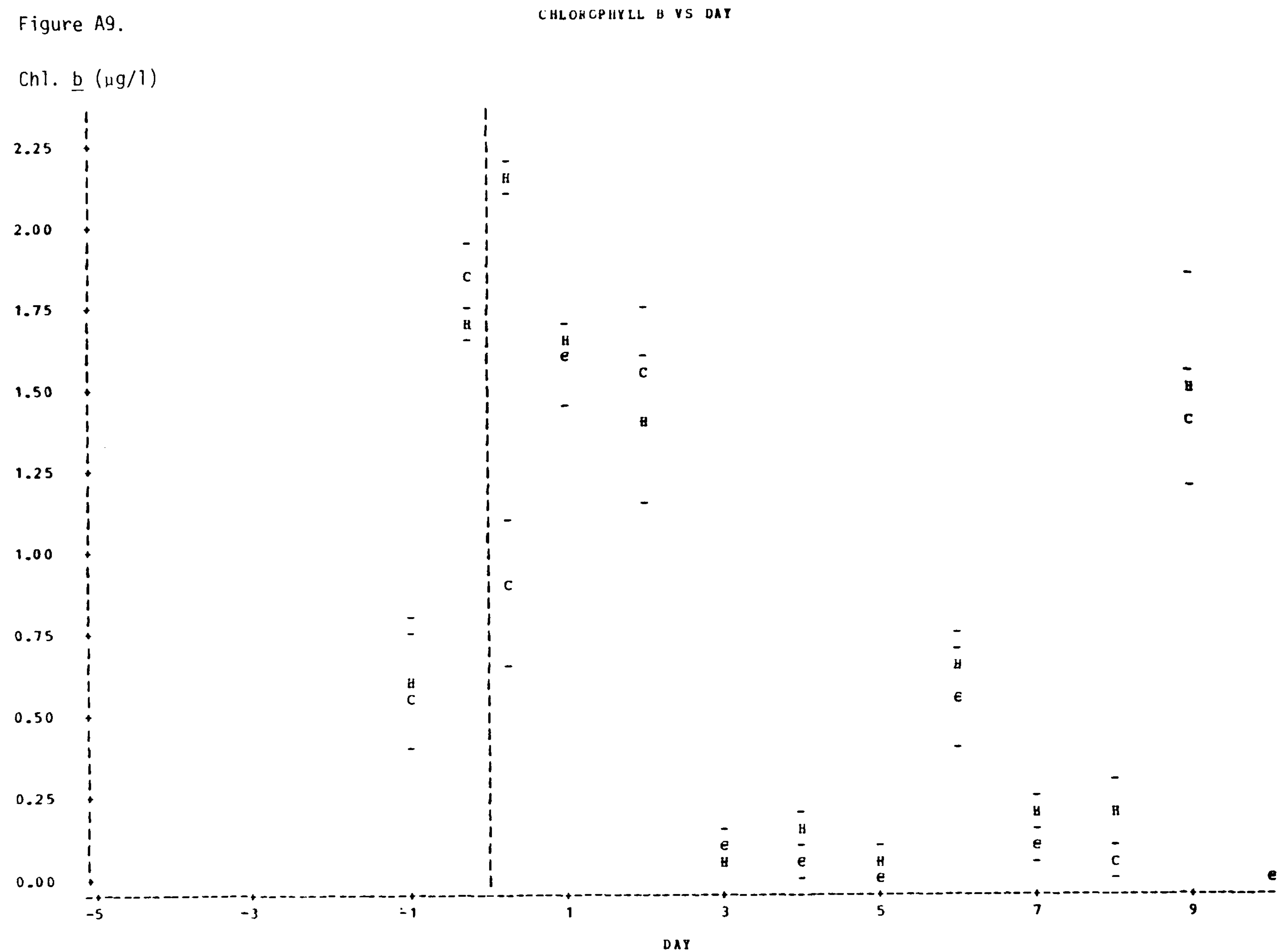

CHLOROPHYLL B VS DAY
Chl. b (μg/l)
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-5
-3
-1
1
3
5
7
9
DAY

Figure A10.

Chl. c (μg/l)

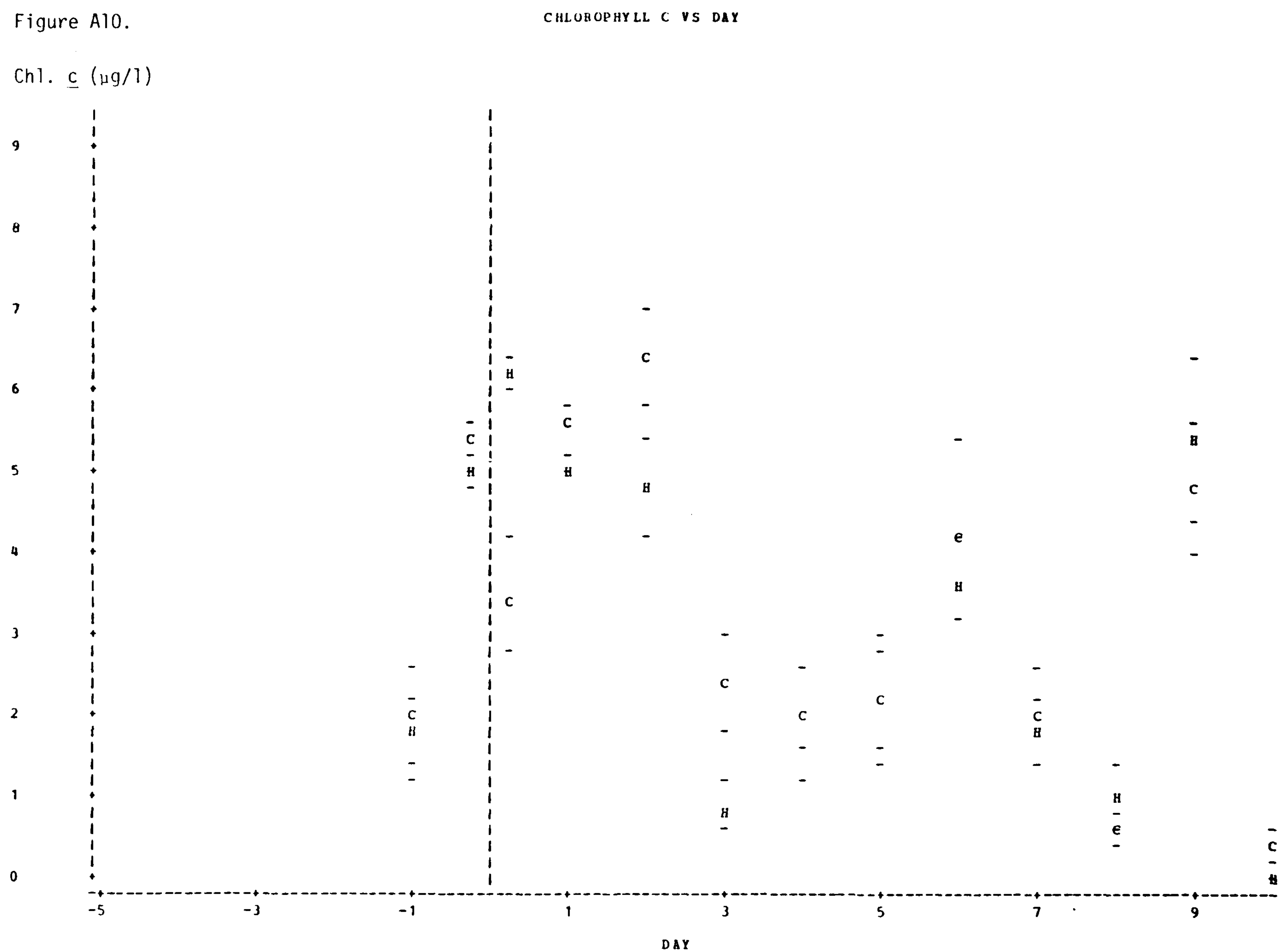
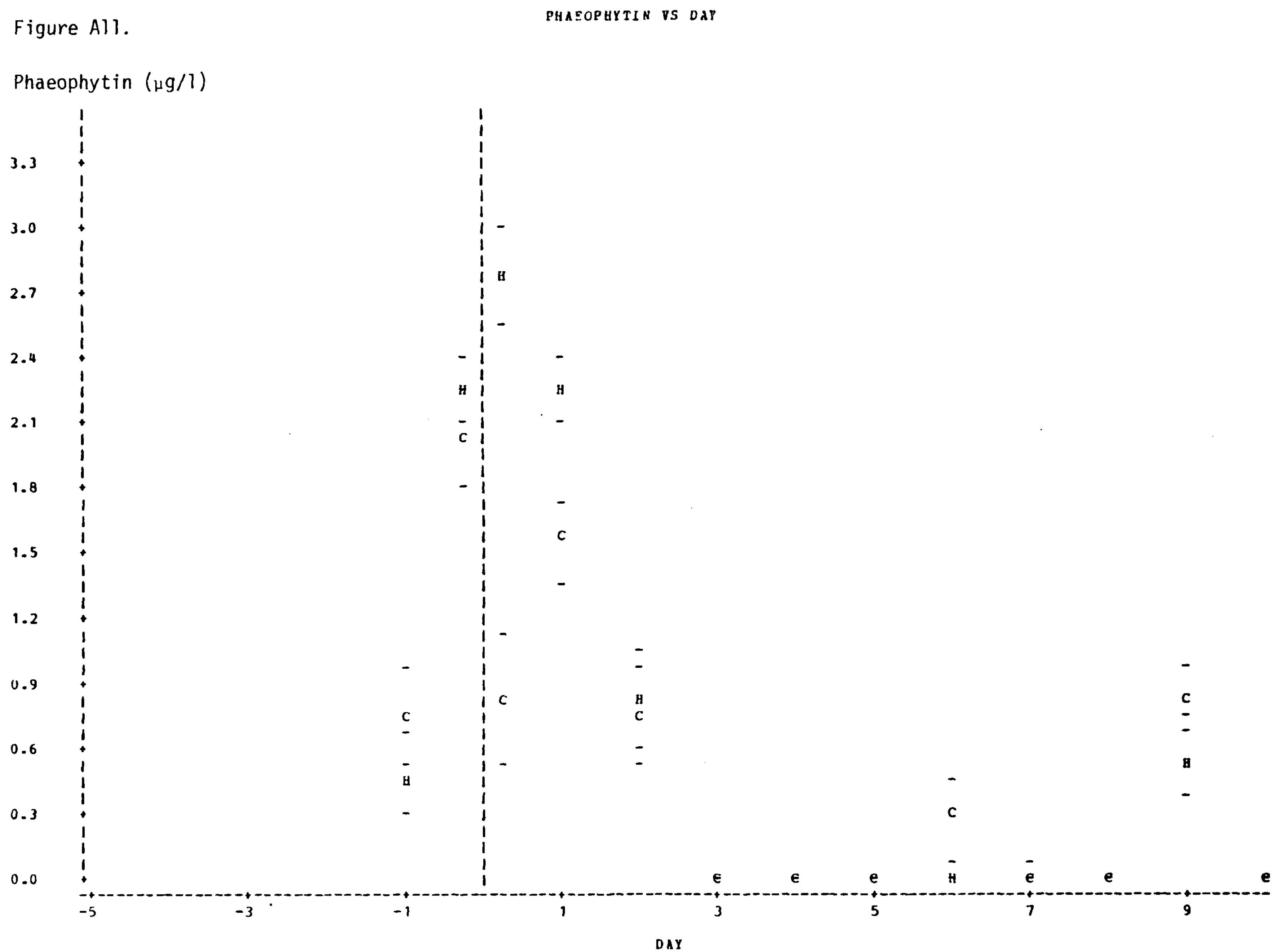


Figure A11.

Phaeophytin (µg/l)



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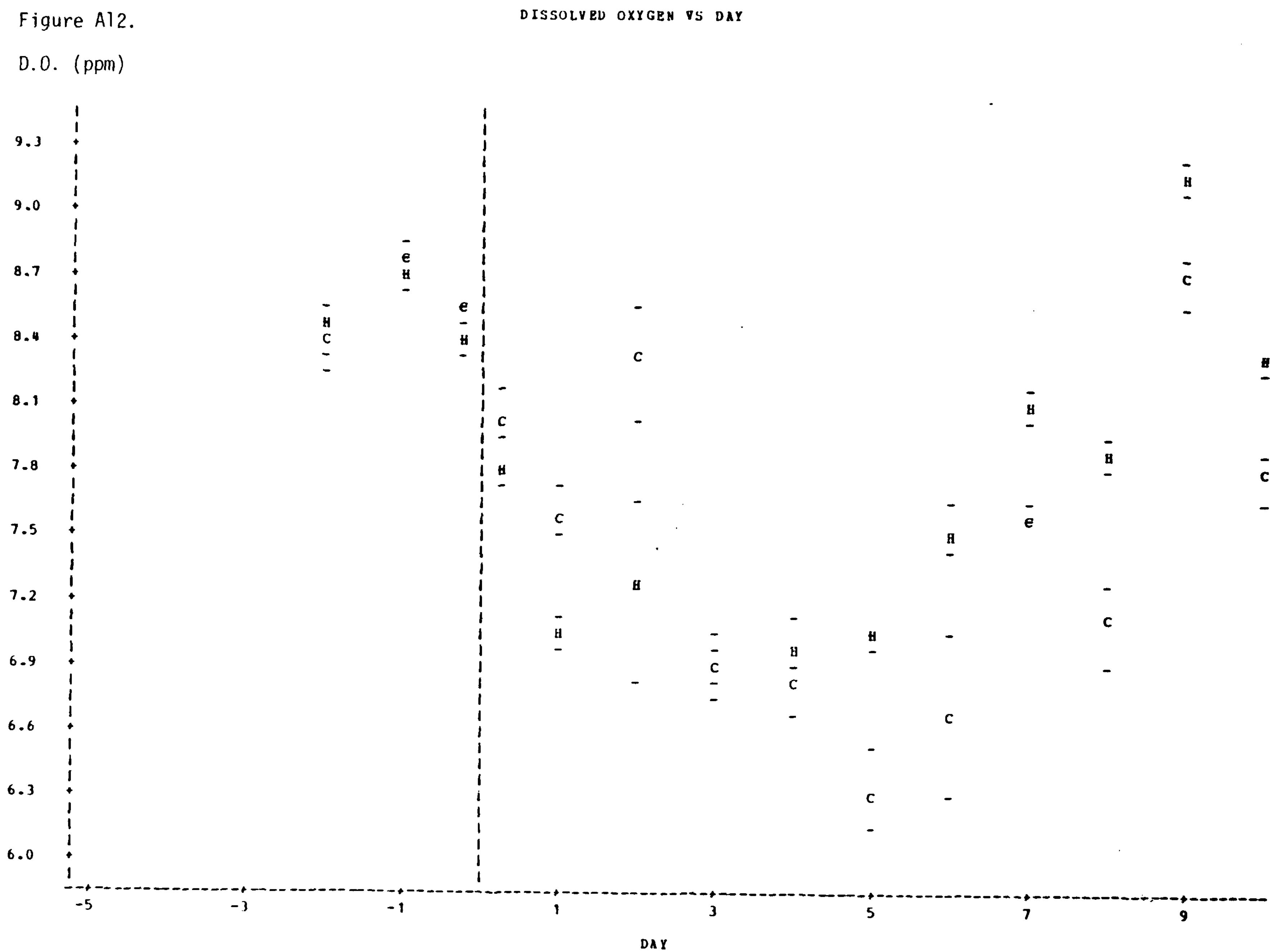


D.O. (ppm)
DISSOLVED OXYGEN VS DAY
9.3
9.0
8.7
8.4
8.1
7.8
7.5
7.2
6.9
6.6
6.3
6.0
-5
-3
-1
1
3
5
7
9
DAY

Figure A13.

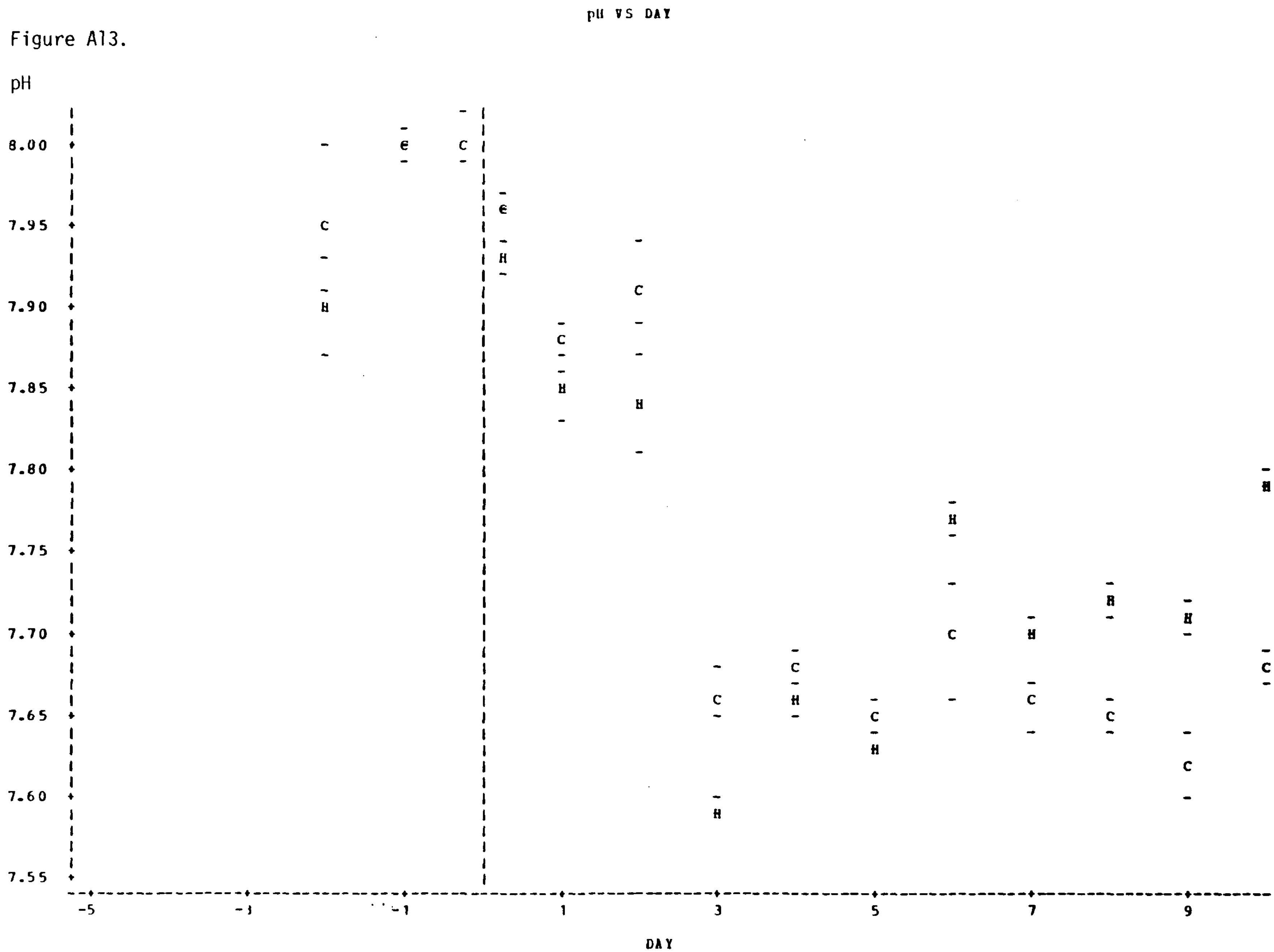


Figure A14.

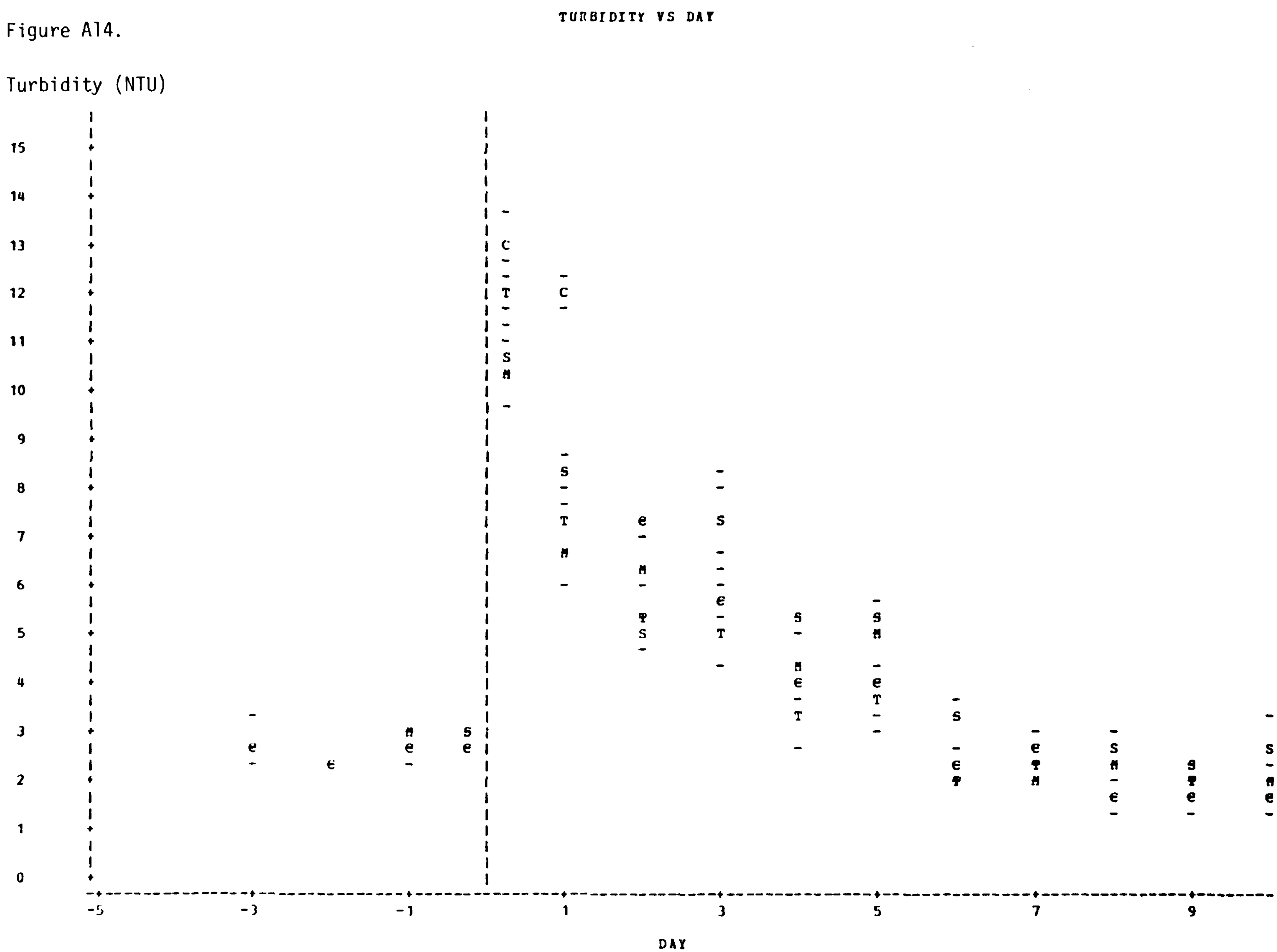

TURBIDITY VS DAY
Turbidity (NTU)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-5
-3
-1
1
3
5
7
9
DAY

Figure A15.

Suspended Solids (mg/l)

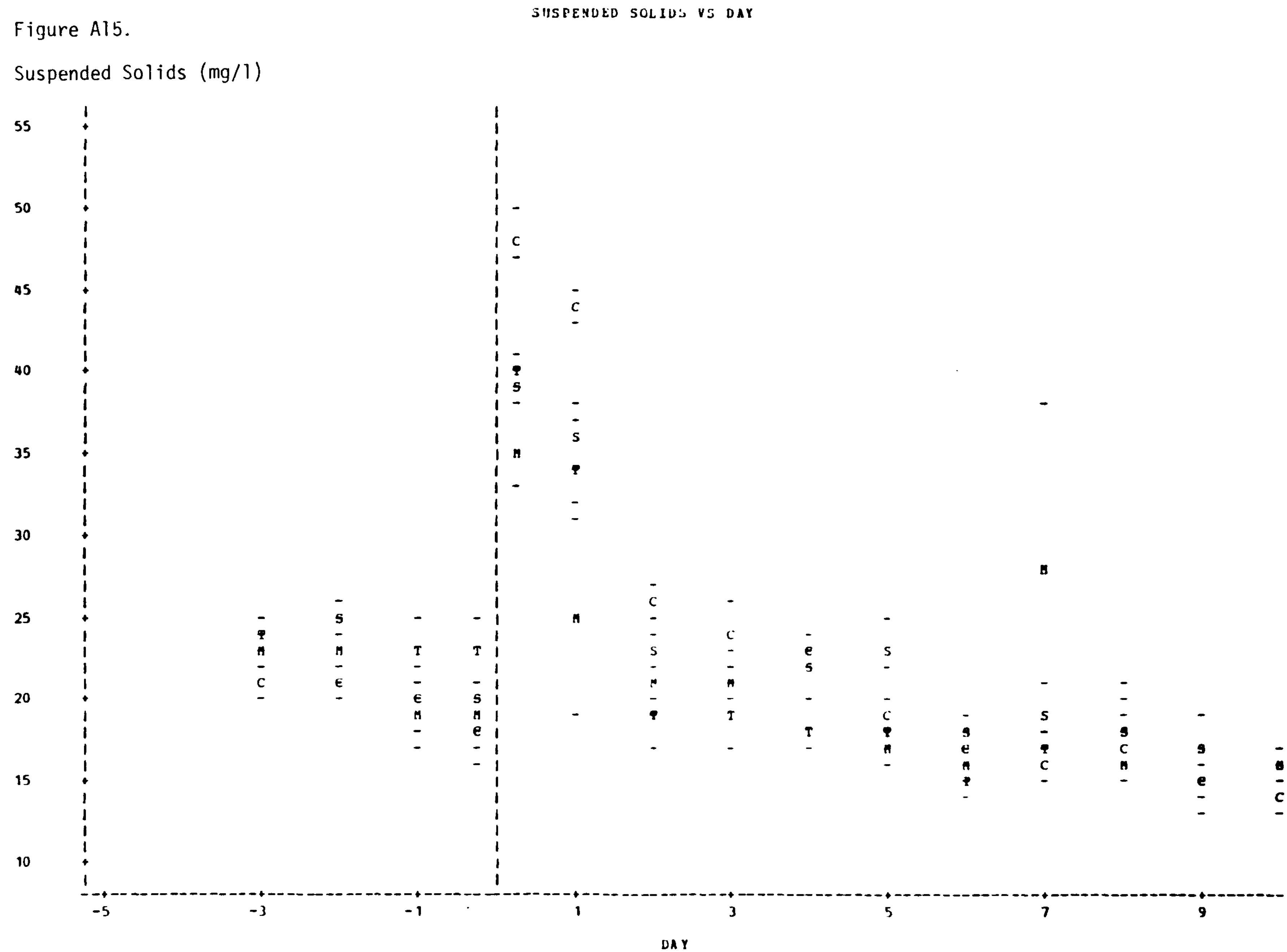


Figure A16.

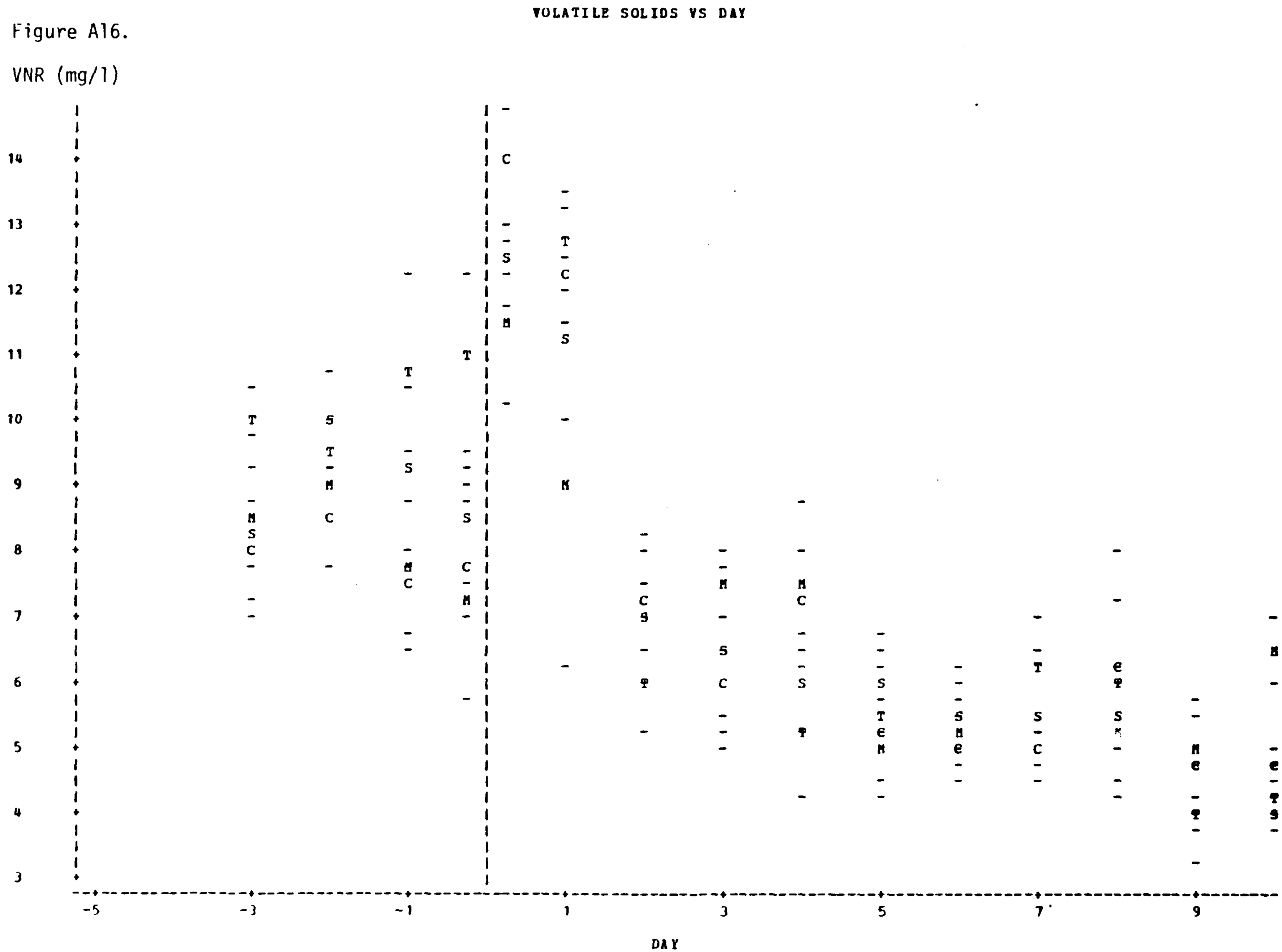
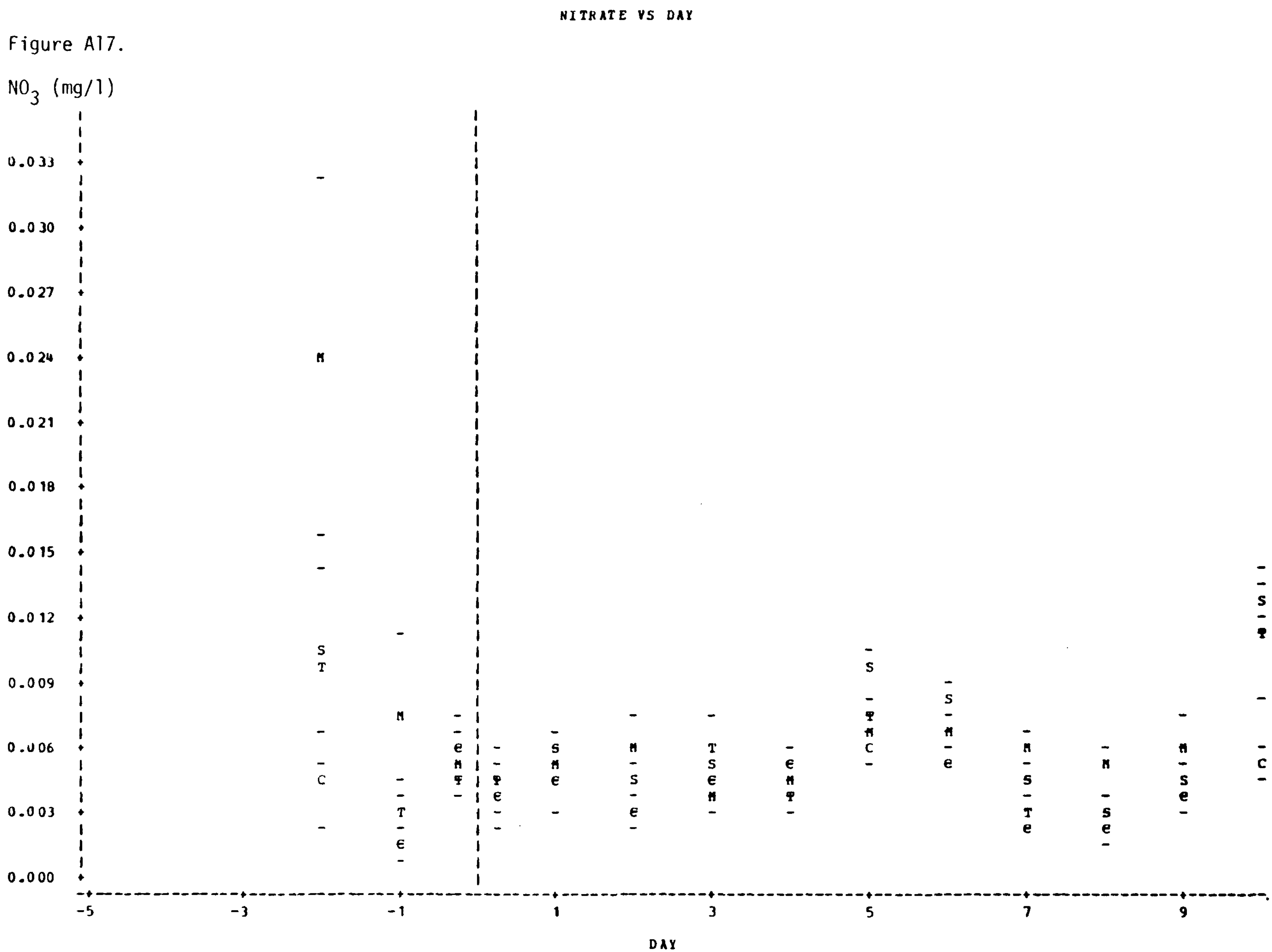


Figure A17.



NITRATE VS DAY
NO_3 (mg/l)
0.033
0.030
0.027
0.024
0.021
0.018
0.015
0.012
0.009
0.006
0.003
0.000
-5
-3
-1
1
3
5
7
9
DAY

NITRITE VS DAY

Figure A18.

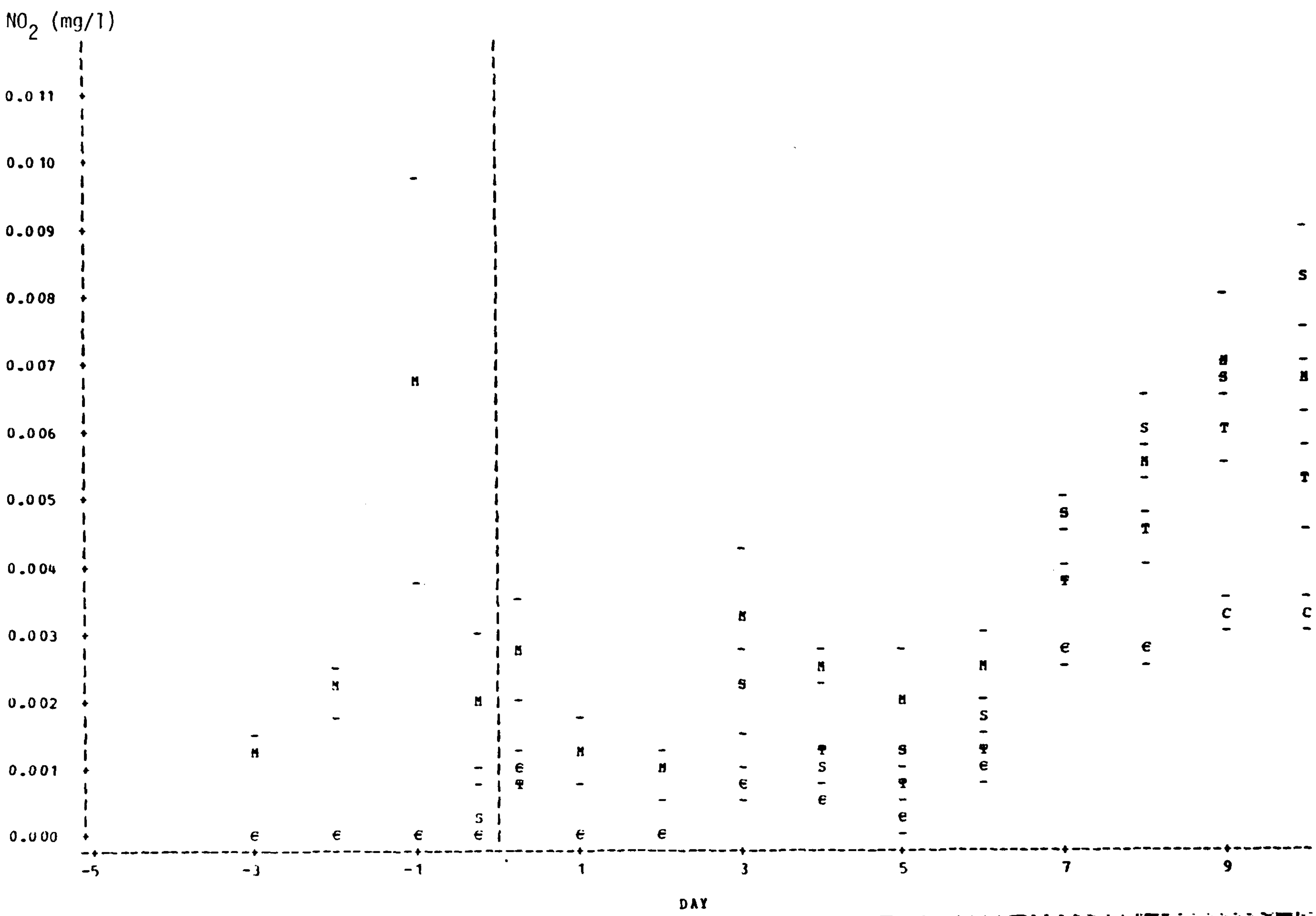
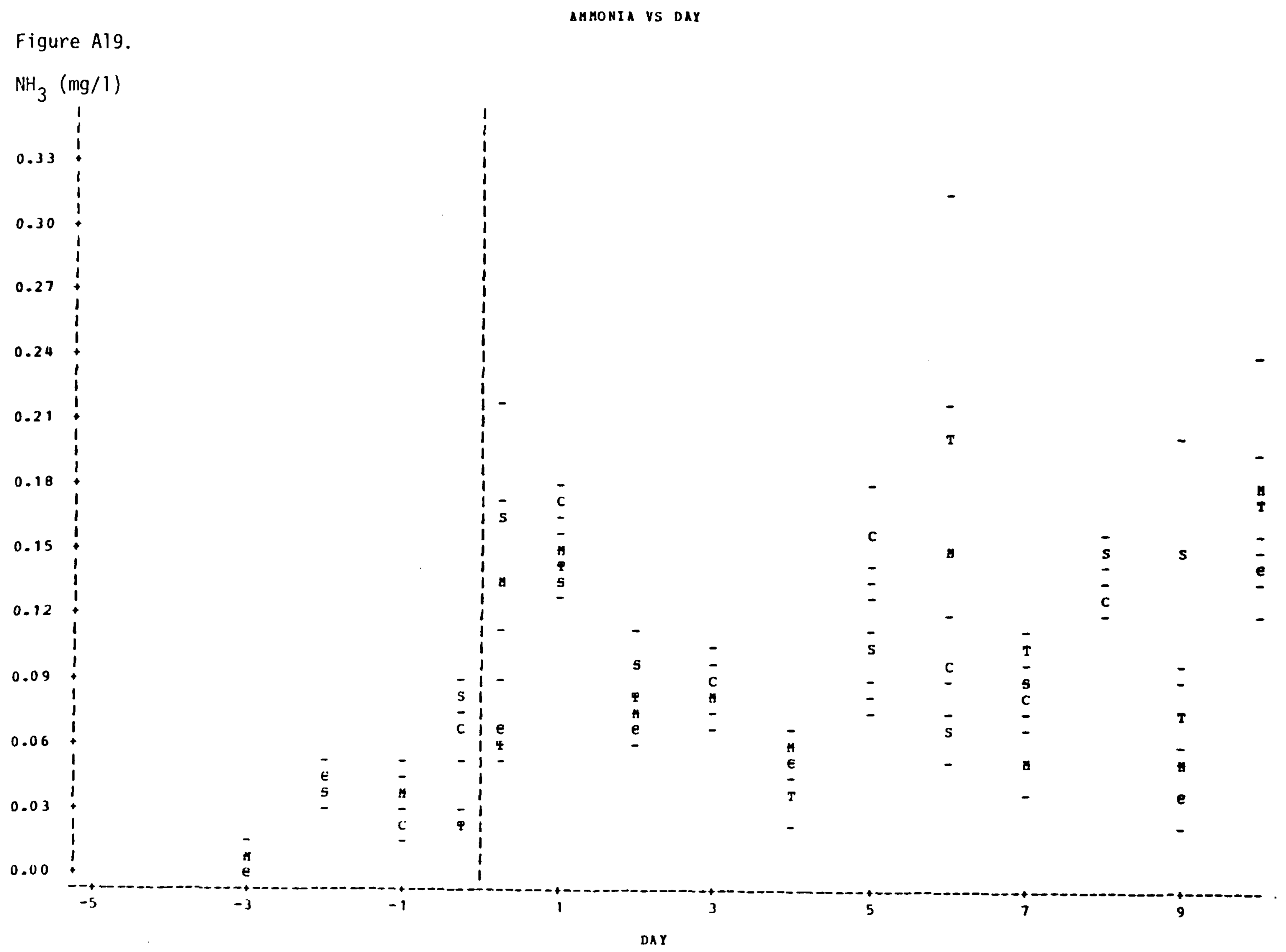


Figure A19.



AMMONIA VS DAY
NH_3 (mg/l)
0.33
0.30
0.27
0.24
0.21
0.18
0.15
0.12
0.09
0.06
0.03
0.00
-5
-3
-1
1
3
5
7
9
DAY

Figure A20.

TOTAL KJELDHAL NITROGEN VS DAY

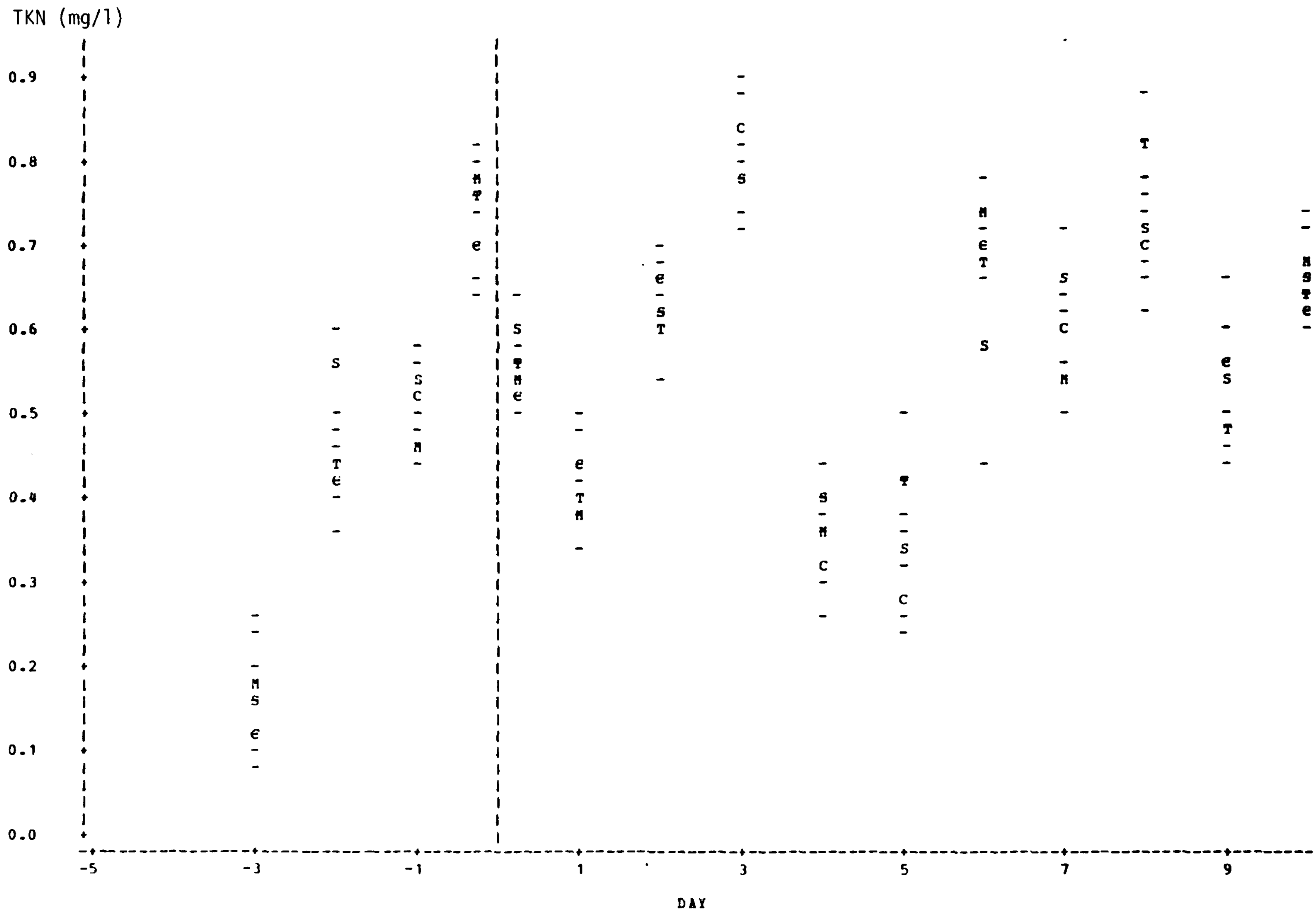


Figure A21.

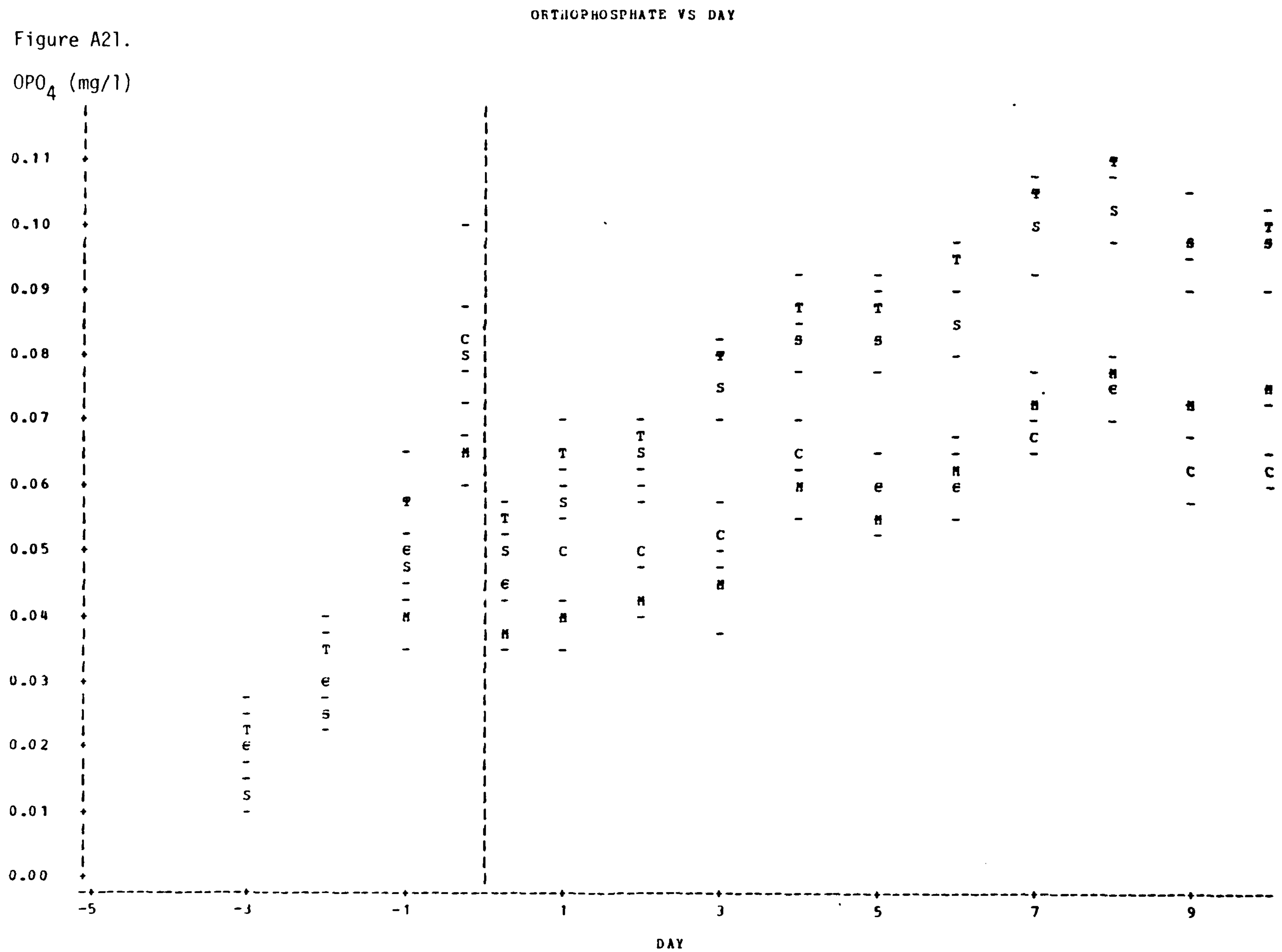
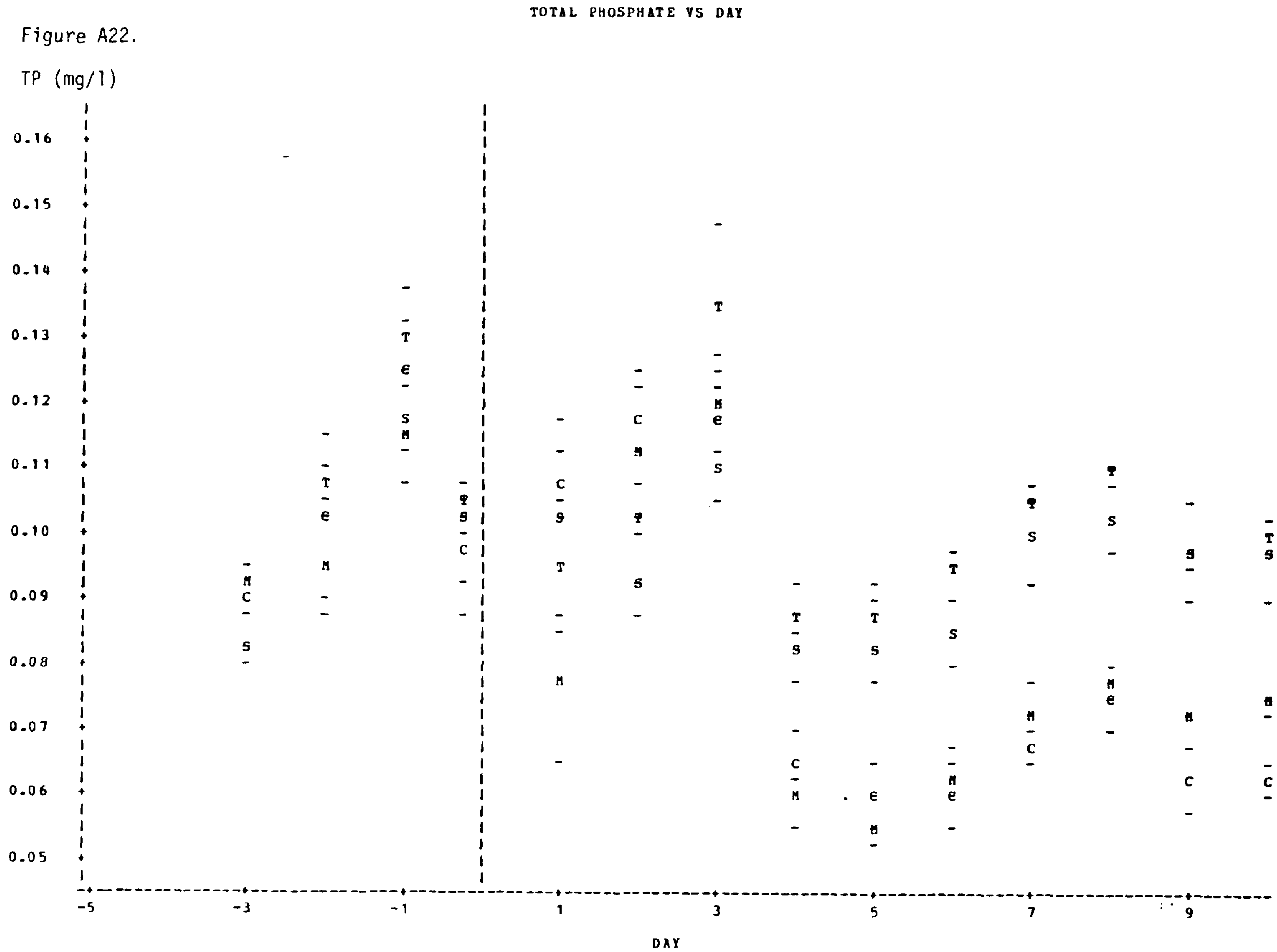

ORTHOPHOSPHATE VS DAY
OPO4 (mg/l)
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-5
-3
-1
1
3
5
7
9
DAY

Figure A22.



TOTAL PHOSPHATE VS DAY
TP (mg/l)
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
-5
-3
-1
1
3
5
7
9
DAY

Figure A23.

Chl. a (μg/l)

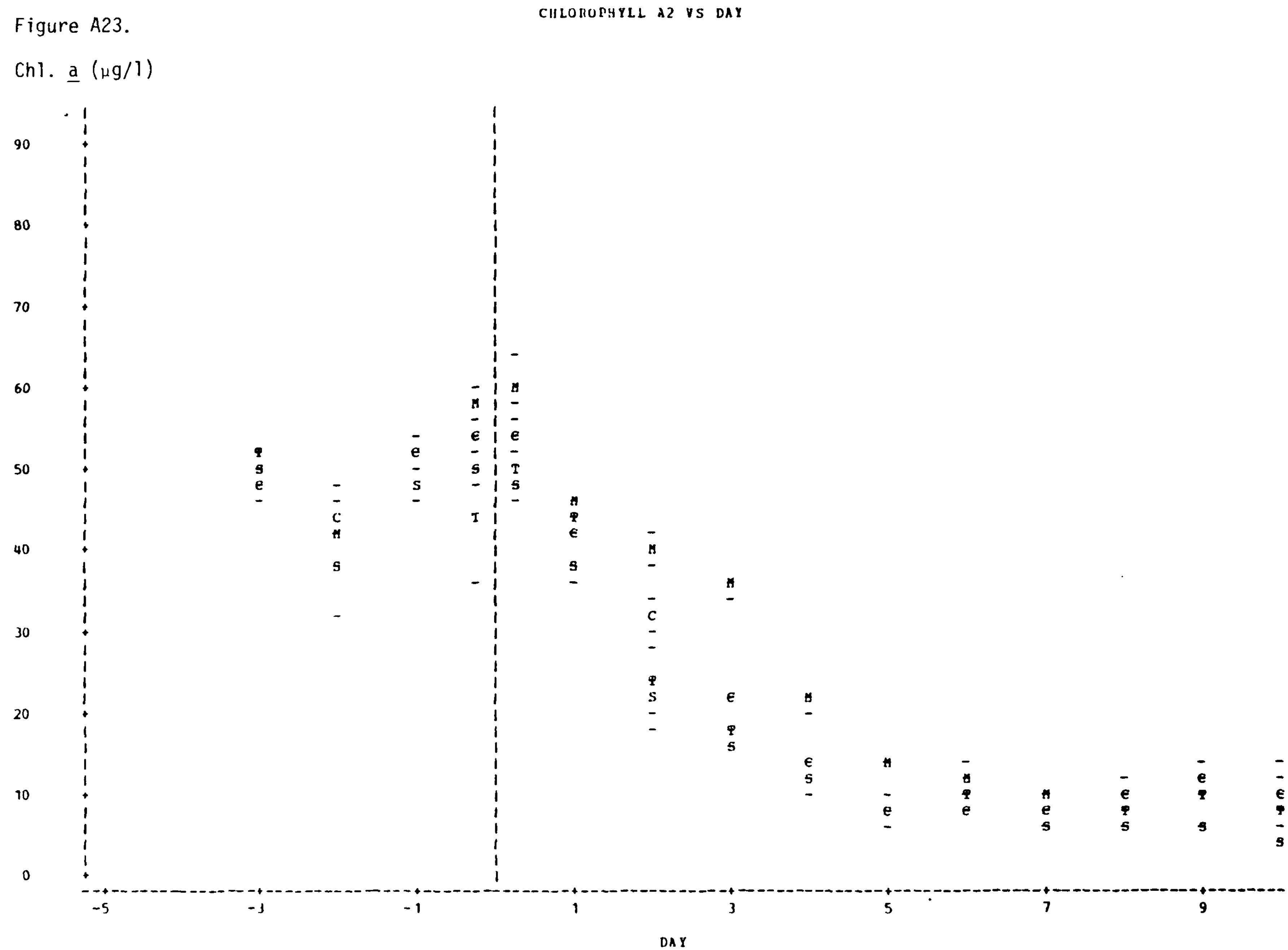


Figure A24.

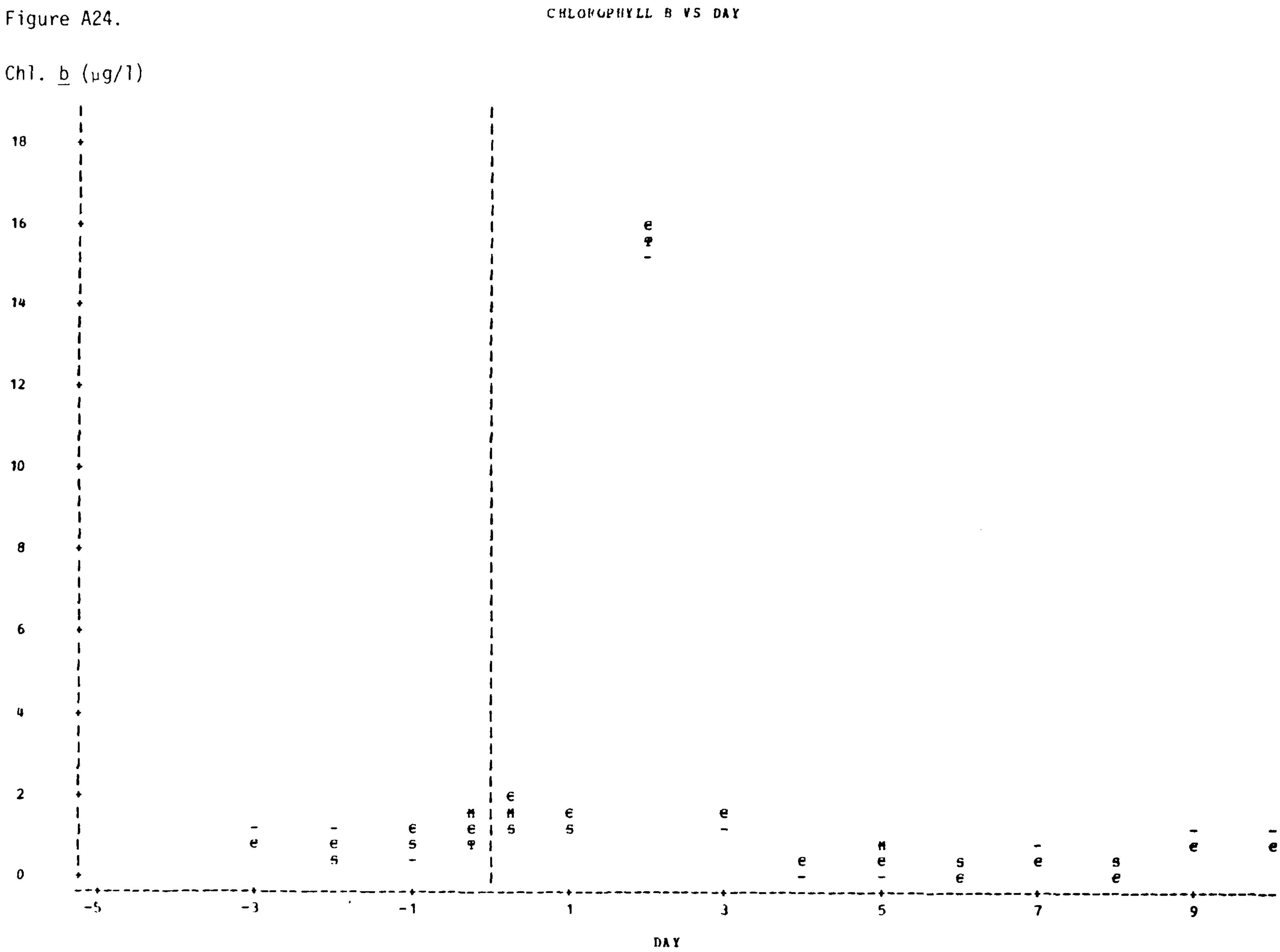
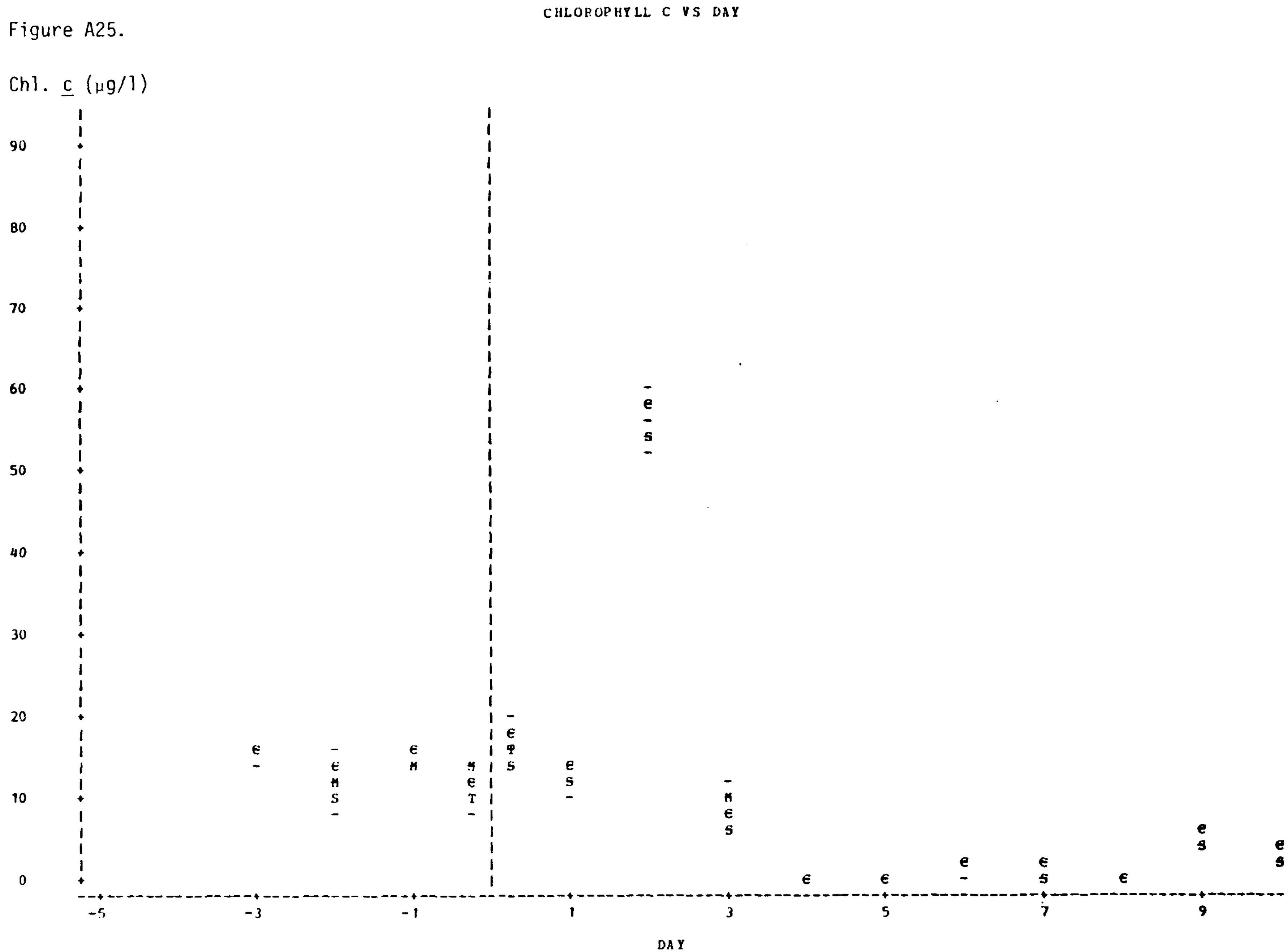

CHLOROPHYLL B VS DAY
Chl. b (μg/l)
18
16
14
12
10
8
6
4
2
0
-5
-3
-1
1
3
5
7
9
DAY

Figure A25.

Chl. c (µg/l)



PHAEOPHYTIN VS DAY

Figure A26.

Phaeophytin (μg/l)

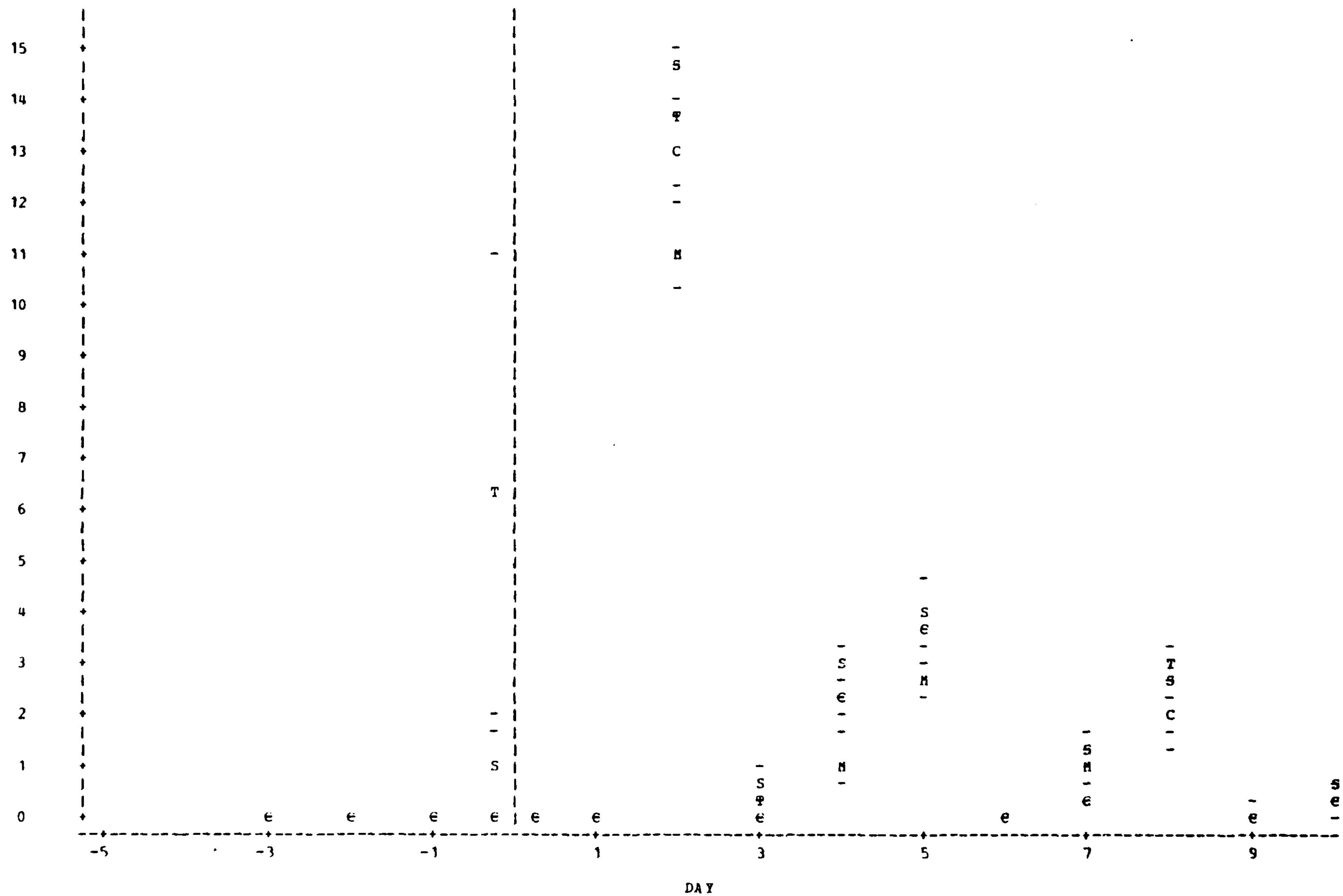


Figure A27.

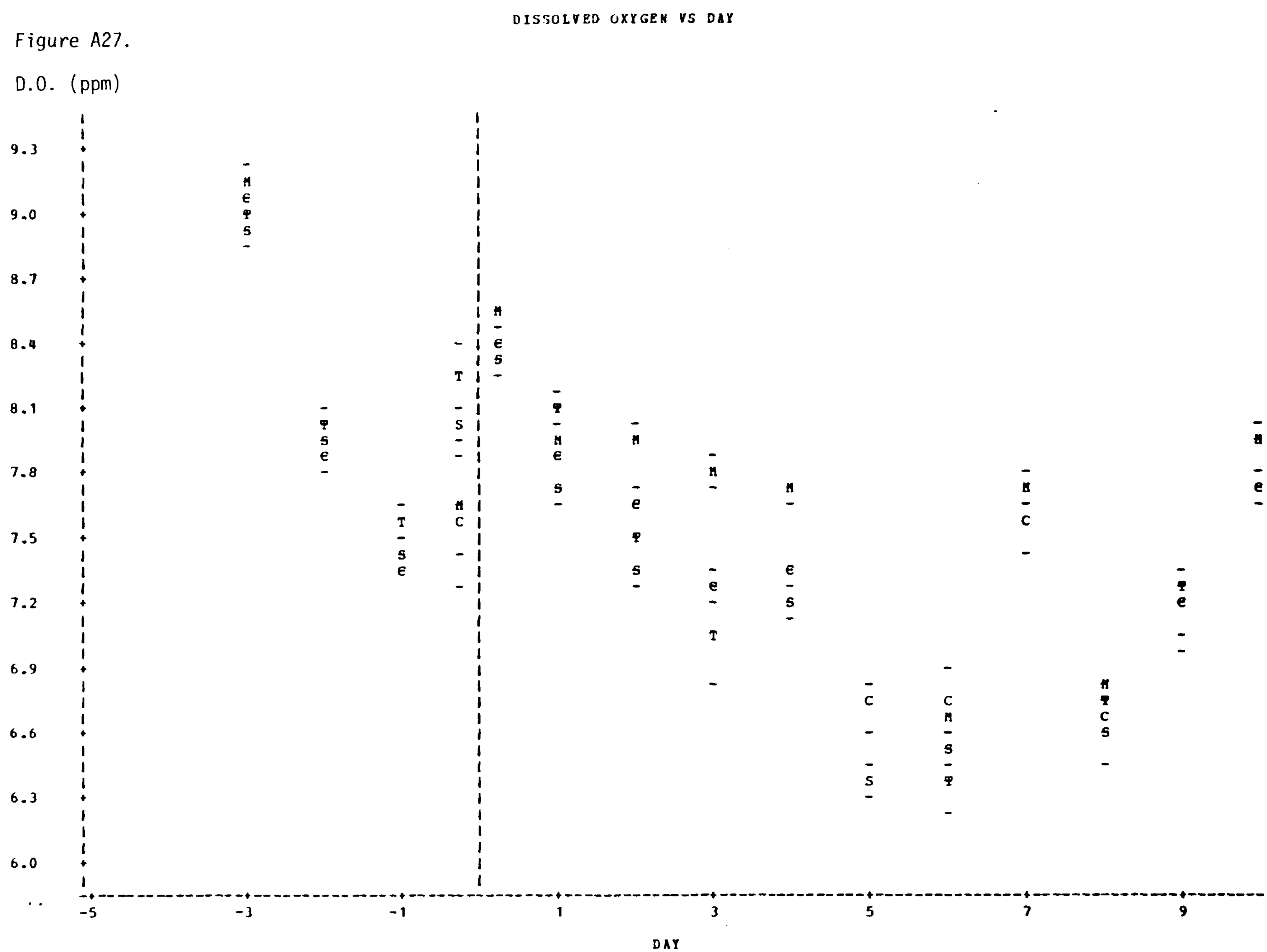
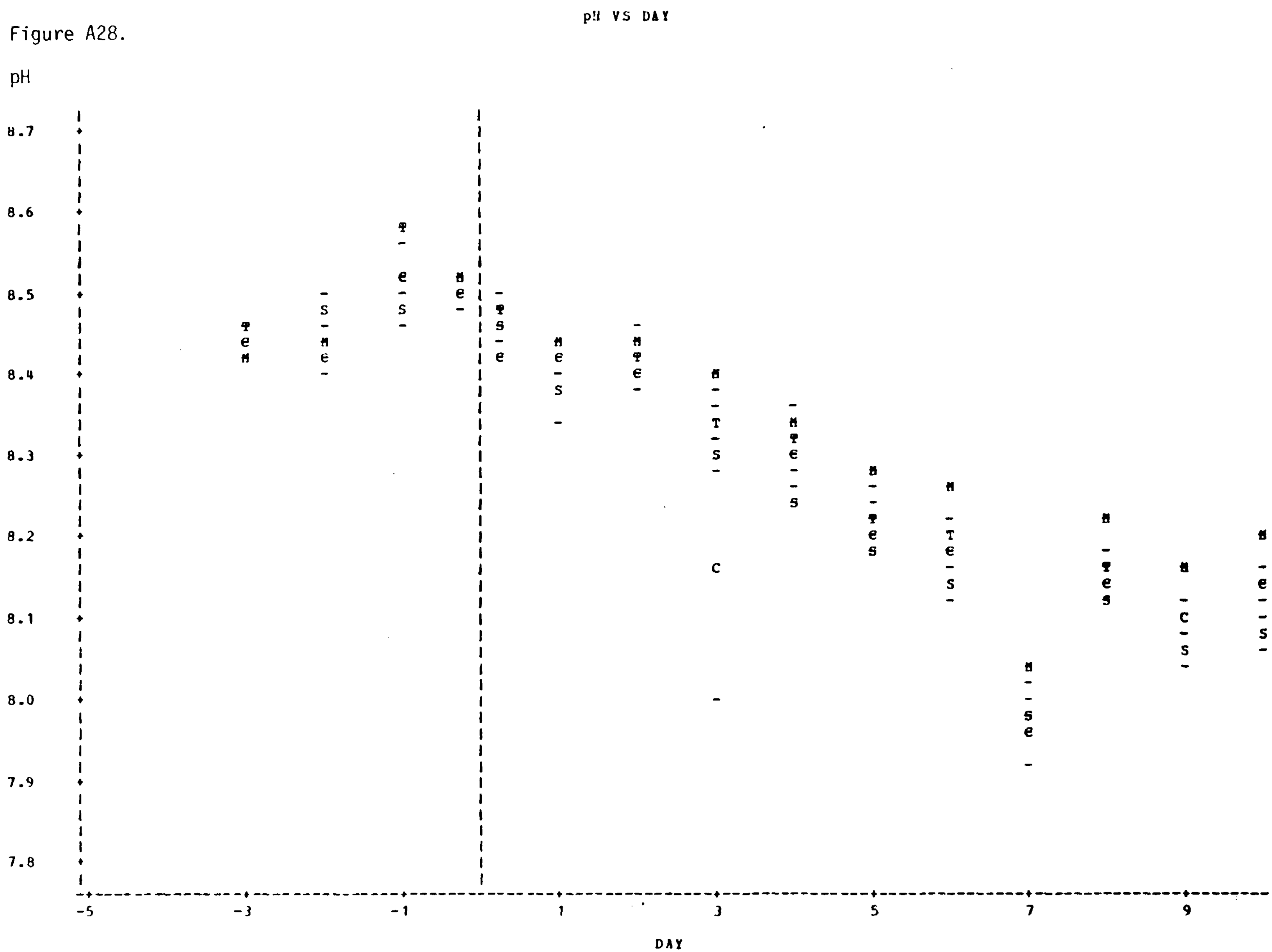

DISSOLVED OXYGEN VS DAY
D.O. (ppm)
9.3
9.0
8.7
8.4
8.1
7.8
7.5
7.2
6.9
6.6
6.3
6.0
-5
-3
-1
1
3
5
7
9
DAY

Figure A28.



APPENDIX B

Zooplankton taxa (#/cu.m.) in microcosm #1. The multivariate (MANOVA) tests of differences between treatments were as follows:

Before Dump (Day 0)		End of Experiment (Day 10)	
Wilk's	= 0.77	Wilk's	= 0.72
F	= 0.31	F	= 0.73
d.f.	= 11, 12	d.f.	= 8, 15
p	= 0.97	p	= 0.66

Figure B1.

ZOOPLANKTON TAXA (#/CU.M.) IN MICROCOSM TREATMENTS

TREATMENT	DAY OF COLLECTION		Acartia tonsa	Centropages typicus	Centropages hamatus	Parvocalanus crassito-stris	Temora longicornis	Pseudodiap-tomus coronatus
CONTROL	BEFORE DUMP	MEAN	20223.21	401.79	475.19	2946.43	580.36	44.64
		STANDARD ERROR	2082.61	258.33	385.97	585.49	273.77	32.04
	END OF EXPERIMENT	MEAN	8809.52	282.74	372.02	1205.36	342.26	163.69
		STANDARD ERROR	2597.10	168.06	284.44	433.04	342.26	83.58
HAMPTON ROADS SEDIMENT	BEFORE DUMP	MEAN	21190.48	133.93	193.45	3125.00	401.79	29.76
		STANDARD ERROR	1544.96	49.76	83.64	650.75	254.56	29.76
	END OF EXPERIMENT	MEAN	7767.86	208.33	44.64	744.05	223.21	238.10
		STANDARD ERROR	951.41	84.66	23.31	187.59	160.21	108.43

TREATMENT	DAY OF COLLECTION		Euterpina acutifrons	Alteutha depressa	Oithona similis	Oithona colcarva	Saphirella sp.	Microstella norvegica
CONTROL	BEFORE DUMP	MEAN	29.76	0.00	14464.29	3258.93	14.88	312.50
		STANDARD ERROR	29.76	0.00	1210.13	566.88	14.88	96.13
	END OF EXPERIMENT	MEAN	0.00	0.00	20223.21	1101.19	44.64	44.64
		STANDARD ERROR	0.00	0.00	6464.70	267.26	32.04	32.04
HAMPTON ROADS SEDIMENT	BEFORE DUMP	MEAN	44.64	0.00	14047.62	4226.19	386.90	431.55
		STANDARD ERROR	32.04	0.00	1005.20	882.06	253.33	104.17
	END OF EXPERIMENT	MEAN	0.00	14.88	10119.05	684.52	59.52	74.40
		STANDARD ERROR	0.00	14.88	1103.71	211.78	25.38	34.46

Figure B2.

ZOOPLANKTON TAXA (#/CU.M.) IN MICROCOSM TREATMENTS

TREATMENT	DAY OF COLLECTION		Copepod 1	Copepod nauplii	Edotea triloba	Ampelisca sp.	Crangon septem-spinosa	Callianassa spp.
CONTROL	BEFORE DUMP	MEAN	0.00	8675.60	0.00	0.00	29.76	238.10
		STANDARD ERROR	0.00	2532.78	0.00	0.00	20.07	163.51
	END OF EXPERIMENT	MEAN	14.88	2395.83	29.76	0.00	0.00	29.76
		STANDARD ERROR	14.88	519.90	29.76	0.00	0.00	20.07
HAMPTON ROADS SEDIMENT	BEFORE DUMP	MEAN	0.00	5639.88	0.00	0.00	89.29	119.05
		STANDARD ERROR	0.00	1174.16	0.00	0.00	74.54	63.45
	END OF EXPERIMENT	MEAN	0.00	4717.26	0.00	163.69	0.00	14.88
		STANDARD ERROR	0.00	1902.75	0.00	163.69	0.00	14.88

TREATMENT	DAY OF COLLECTION		Upogebia affinis	Pagurus longicarpus z.	Callinectes spp. z.	Portunus sp. z.	Portunidae z.	Hexapanopeus angustifrons z.
CONTROL	BEFORE DUMP	MEAN	59.52	44.64	312.50	14.88	14.88	14.88
		STANDARD ERROR	33.58	32.04	95.13	14.88	14.88	14.88
	END OF EXPERIMENT	MEAN	0.00	14.88	104.17	0.00	0.00	0.00
		STANDARD ERROR	0.00	14.88	89.17	0.00	0.00	0.00
HAMPTON ROADS SEDIMENT	BEFORE DUMP	MEAN	89.29	0.00	431.55	44.64	0.00	0.00
		STANDARD ERROR	51.55	0.00	95.96	44.64	0.00	0.00
	END OF EXPERIMENT	MEAN	0.00	0.00	44.64	0.00	29.76	0.00
		STANDARD ERROR	0.00	0.00	44.64	0.00	20.07	0.00

Figure B3.

ZOOPLANKTON TAXA (#/CU.M.) IN MICROCOSM TREATMENTS

TREATMENT	DAY OF COLLECTION		Neopanope texana sayi z.	Rithropanopeus harrisii z.	Pinnixa chaetopterana z.	Pinnixa cylindrica z.	Pinnixa sayana z.	Emerita talpoida
CONTROL	BEFORE DUMP	MEAN	29.76	14.88	610.12	44.64	14.88	44.64
		STANDARD ERROR	20.07	14.88	130.89	32.04	14.88	23.31
	END OF EXPERIMENT	MEAN	0.00	0.00	14.88	0.00	0.00	14.88
		STANDARD ERROR	0.00	0.00	14.88	0.00	0.00	14.88
HAMPTON ROADS SEDIMENT	BEFORE DUMP	MEAN	0.00	0.00	401.79	44.64	163.69	0.00
		STANDARD ERROR	0.00	0.00	122.63	23.31	132.72	0.00
	END OF EXPERIMENT	MEAN	14.88	14.88	14.88	0.00	0.00	0.00
		STANDARD ERROR	14.88	14.88	14.88	0.00	0.00	0.00

TREATMENT	DAY OF COLLECTION		Uca (minax) sp z.	Squilla empusa	Neomysis americana	Oxyurustylis smithi	barnacle nauplii	barnacle cypriid
CONTROL	BEFORE DUMP	MEAN	0.00	0.00	14.88	0.00	252.98	357.14
		STANDARD ERROR	0.00	0.00	14.88	0.00	104.17	280.63
	END OF EXPERIMENT	MEAN	29.76	14.88	0.00	0.00	44.64	59.52
		STANDARD ERROR	20.07	14.88	0.00	0.00	32.04	45.76
HAMPTON ROADS SEDIMENT	BEFORE DUMP	MEAN	0.00	14.88	0.00	14.88	119.05	193.45
		STANDARD ERROR	0.00	14.88	0.00	14.88	59.52	71.08
	END OF EXPERIMENT	MEAN	0.00	0.00	0.00	0.00	14.88	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	14.88	0.00

Figure B4.

ZOOPLANKTON TAXA (#/CU.M.) IN MICROCOSM TREATMENTS

TREATMENT	DAY OF COLLECTION		bivalve b1	bivalve b2	bivalve b3	bivalve f	gastropod e	gastropod f
CONTROL	BEFORE DUMP	MEAN	1190.48	29.76	0.00	44.64	0.00	1517.86
		STANDARD ERROR	944.23	20.07	0.00	23.31	0.00	1469.34
	END OF EXPERIMENT	MEAN	0.00	0.00	0.00	0.00	0.00	44.64
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	32.04
HAMPTON ROADS SEDIMENT	BEFORE DUMP	MEAN	833.33	104.17	14.88	14.88	208.33	892.86
		STANDARD ERROR	533.15	51.35	14.88	14.88	178.35	519.23
	END OF EXPERIMENT	MEAN	0.00	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	0.00

TREATMENT	DAY OF COLLECTION		gastropod g	Mysella bidentata	Crepidula sp.	Polychaete a	Polychaete f	Spionid
CONTROL	BEFORE DUMP	MEAN	0.00	0.00	193.45	0.00	0.00	44.64
		STANDARD ERROR	0.00	0.00	193.45	0.00	0.00	32.04
	END OF EXPERIMENT	MEAN	0.00	0.00	0.00	29.76	0.00	44.64
		STANDARD ERROR	0.00	0.00	0.00	20.07	0.00	23.31
HAMPTON ROADS SEDIMENT	BEFORE DUMP	MEAN	29.76	14.88	0.00	0.00	0.00	74.40
		STANDARD ERROR	20.07	14.88	0.00	0.00	0.00	60.03
	END OF EXPERIMENT	MEAN	0.00	0.00	0.00	0.00	14.88	29.76
		STANDARD ERROR	0.00	0.00	0.00	0.00	14.88	29.76

Figure B5.

ZOOPLANKTON TAXA (#/CU.M.) IN MICROCOSM TREATMENTS

TREATMENT	DAY OF COLLECTION		Nereid	Poly.	Podon sp.	Evadne sp.	Penilia avirostria	Larvacean
CONTROL	BEFORE DUMP	MEAN	29.76	0.00	1130.95	104.17	3348.21	44.64
		STANDARD ERROR	29.76	0.00	927.19	89.17	768.10	32.04
	END OF EXPERIMENT	MEAN	0.00	0.00	446.43	0.00	416.67	0.00
		STANDARD ERROR	0.00	0.00	445.43	0.00	309.56	0.00
HAMPTON ROADS SEDIMENT	BEFORE DUMP	MEAN	14.88	14.88	89.29	401.79	4464.29	59.52
		STANDARD ERROR	14.88	14.88	89.29	284.16	521.55	45.76
	END OF EXPERIMENT	MEAN	0.00	0.00	252.98	59.52	327.38	44.64
		STANDARD ERROR	0.00	0.00	119.30	59.52	148.81	32.04

TREATMENT	DAY OF COLLECTION		Phoronis sp.	Nematoda	Foraminifera	Ammodytes hexapterus	Anchoa mitchilli	Scopthalmus aquosus
CONTROL	BEFORE DUMP	MEAN	0.00	133.93	0.00	0.00	89.29	29.76
		STANDARD ERROR	0.00	44.64	0.00	0.00	34.75	29.76
	END OF EXPERIMENT	MEAN	0.00	74.40	29.76	0.00	0.00	0.00
		STANDARD ERROR	0.00	34.46	29.07	0.00	0.00	0.00
HAMPTON ROADS SEDIMENT	BEFORE DUMP	MEAN	29.76	178.57	104.17	14.88	89.29	0.00
		STANDARD ERROR	29.76	49.15	89.17	14.88	26.92	0.00
	END OF EXPERIMENT	MEAN	0.00	14.88	0.00	0.00	29.76	0.00
		STANDARD ERROR	0.00	14.88	0.00	0.00	20.07	0.00

Figure B6.

ZOOPLANKTON TAXA (#/CU.M.) IN MICROCOSM TREATMENTS

TREATMENT	DAY OF COLLECTION		Bothidae	f.e. Engraulidae	f.e. Sciaenidae	Echinoidea	Ophioplateus	Bougainvillia carolinensis
CONTROL	BEFORE DUMP	MEAN	44.64	59.52	0.00	0.00	14.88	59.52
		STANDARD ERROR	23.31	33.58	0.00	0.00	14.88	45.76
	END OF EXPERIMENT	MEAN	0.00	44.64	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	44.64	0.00	0.00	0.00	0.00
HAMPTON ROADS SEDIMENT	BEFORE DUMP	MEAN	0.00	104.17	14.88	0.00	0.00	44.64
		STANDARD ERROR	0.00	60.03	14.88	0.00	0.00	23.31
	END OF EXPERIMENT	MEAN	0.00	0.00	0.00	14.88	0.00	29.76
		STANDARD ERROR	0.00	0.00	0.00	14.88	0.00	20.07

TREATMENT	DAY OF COLLECTION		Podocoryne minimc	Gastropod I	Uca megalopa	Andara	Eurypanopeus depressus z.	Medusa 1 unid
CONTROL	BEFORE DUMP	MEAN	0.00	0.00	0.00	0.00	14.88	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	14.88	0.00
	END OF EXPERIMENT	MEAN	0.00	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	0.00
HAMPTON ROADS SEDIMENT	BEFORE DUMP	MEAN	0.00	14.88	14.88	29.76	0.00	0.00
		STANDARD ERROR	0.00	14.88	14.88	20.07	0.00	0.00
	END OF EXPERIMENT	MEAN	29.76	0.00	0.00	14.88	0.00	29.76
		STANDARD ERROR	29.76	0.00	0.00	14.88	0.00	20.07

Figure B7.

ZOOPLANKTON TAXA (#/CU.M.) IN MICROCOSM TREATMENTS

TREATMENT	DAY OF COLLECTION		Pinnotheres maculatus
CONTROL	BEFORE DUMP	MEAN	0.00
		STANDARD ERROR	0.00
	END OF EXPERIMENT	MEAN	29.76
		STANDARD ERROR	29.76
HAMPTON ROADS SEDIMENT	BEFORE DUMP	MEAN	0.00
		STANDARD ERROR	0.00
	END OF EXPERIMENT	MEAN	0.00
		STANDARD ERROR	0.00

APPENDIX C

Zooplankton taxa (#/cu.m.) in microcosm #2. The multivariate (MANOVA) tests of differences between treatments were as follows:

Before		After	
Wilk's	= 0.23	Wilk's	= 0.33
F	= 1.40	F	= 0.91
d.f.	= 21, 41	d.f.	= 21, 41
p	= 0.34	p	= 0.58

Figure C1.

ZOOPLANKTON TAXA (#/CU.M.) IN MICROCOSM TREATMENTS

TREATMENT	DAY OF COLLECTION		Acartia tonsa	Centropages typicus	Centropages spp.	Parvocalanus crassirostris	Temora longicornis	Pseudodiaptomus coronatus
CONTROL	PRE-DUMP	MEAN	10535.71	12113.10	982.14	4226.19	5119.05	5416.67
		STANDARD ERROR	1736.83	1446.62	204.90	591.66	631.63	706.30
	POST-DUMP	MEAN	8244.05	7142.86	0.00	744.05	3452.38	1279.76
		STANDARD ERROR	1204.46	601.16	0.00	116.79	554.56	155.79
SOUTH BRANCH OF E.R.	PRE-DUMP	MEAN	17619.05	16607.14	2589.29	3690.48	8154.76	5803.57
		STANDARD ERROR	5177.07	1615.72	219.92	641.64	431.70	948.00
	POST-DUMP	MEAN	8095.24	8422.62	238.10	833.33	3363.10	1160.71
		STANDARD ERROR	894.84	1242.68	109.76	238.10	534.56	297.92
MAIN STEM OF E.R.	PRE-DUMP	MEAN	14047.62	15297.62	2380.95	3422.62	6220.24	5714.29
		STANDARD ERROR	1616.81	706.30	344.00	372.92	536.54	688.52
	POST-DUMP	MEAN	9226.19	9880.95	535.71	1369.05	3988.10	1994.05
		STANDARD ERROR	1405.82	1100.47	535.71	164.10	612.84	367.17
THIMBLE SHOALS	PRE-DUMP	MEAN	13809.52	17916.67	1994.05	3988.10	6220.24	6369.05
		STANDARD ERROR	1933.56	2153.08	352.40	673.96	714.91	928.65
	POST-DUMP	MEAN	10267.86	10029.76	89.29	833.33	3571.43	1458.33
		STANDARD ERROR	1169.84	1381.22	39.93	75.29	553.28	245.78

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UNCLASSIFIED DACW65-81-C-0051 F/G 8/10 NL

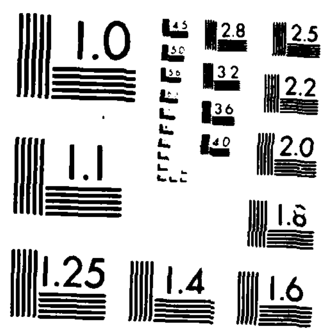

Figure C2.

ZOOPLANKTON TAXA (#/CU.M.) IN MICROCOSM TREATMENTS

TREATMENT	DAY OF COLLECTION		Oithona colcarva	Saphirella sp.	Microstella norvegica	Pontella pennata	copepod nauplii	Crangon septemspinosa
CONTROL	PRE-DUMP	MEAN	892.86	29.76	327.38	0.00	238.10	89.29
		STANDARD ERROR	121.99	29.76	155.79	0.00	59.52	60.99
	POST-DUMP	MEAN	89.29	0.00	59.52	0.00	119.05	0.00
		STANDARD ERROR	60.99	0.00	59.52	0.00	88.29	0.00
SOUTH BRANCH OF E.R.	PRE-DUMP	MEAN	2053.57	29.76	178.57	0.00	505.95	1845.24
		STANDARD ERROR	491.75	29.76	65.21	0.00	372.92	1774.17
	POST-DUMP	MEAN	0.00	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	0.00
MAIN STEM OF E.R.	PRE-DUMP	MEAN	1339.29	0.00	59.52	0.00	59.52	297.62
		STANDARD ERROR	462.80	0.00	37.65	0.00	37.65	88.29
	POST-DUMP	MEAN	59.52	0.00	29.76	0.00	0.00	29.76
		STANDARD ERROR	59.52	0.00	29.76	0.00	0.00	29.76
THIMBLE SHOALS	PRE-DUMP	MEAN	1279.76	0.00	59.52	0.00	208.33	119.05
		STANDARD ERROR	162.47	0.00	37.65	0.00	116.79	88.29
	POST-DUMP	MEAN	0.00	29.76	0.00	29.76	0.00	0.00
		STANDARD ERROR	0.00	29.76	0.00	29.76	0.00	0.00

Figure C3.

ZOOPLANKTON TAXA (#/CU.M.) IN MICROCOSM TREATMENTS

TREATMENT	DAY OF COLLECTION		Pagurus longicarpus	Paleomonetes sp.	Rhithropanopeus harrisii z.	barnacle naupilii	barnacle cypriid	Evadne sp.
CONTROL	PRE-DUMP	MEAN	0.00	0.00	0.00	59.52	29.76	29.76
		STANDARD ERROR	0.00	0.00	0.00	59.52	29.76	29.76
	POST-DUMP	MEAN	59.52	0.00	29.76	0.00	29.76	0.00
		STANDARD ERROR	37.65	0.00	29.76	0.00	29.76	0.00
SOUTH BRANCH OF E.R.	PRE-DUMP	MEAN	0.00	29.76	0.00	535.71	148.81	119.05
		STANDARD ERROR	0.00	29.76	0.00	368.86	85.23	37.65
	POST-DUMP	MEAN	148.81	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	96.90	0.00	0.00	0.00	0.00	0.00
MAIN STEM OF E.R.	PRE-DUMP	MEAN	0.00	0.00	0.00	59.52	89.29	59.52
		STANDARD ERROR	0.00	0.00	0.00	59.52	39.93	59.52
	POST-DUMP	MEAN	654.76	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	324.94	0.00	0.00	0.00	0.00	0.00
THIMBLE SHOALS	PRE-DUMP	MEAN	0.00	0.00	0.00	208.33	29.76	0.00
		STANDARD ERROR	0.00	0.00	0.00	107.31	29.76	0.00
	POST-DUMP	MEAN	505.95	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	438.42	0.00	0.00	0.00	0.00	0.00

Figure C4.

ZOOPLANKTON TAXA (#/CU.M.) IN MICROCOSM TREATMENTS

TREATMENT	DAY OF COLLECTION		Ampelisca verrilli	Spionid spp.	Poly 1	trochophore	Autolytus sp.	Magelonid
CONTROL	PRE-DUMP	MEAN	0.00	327.38	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	96.90	0.00	0.00	0.00	0.00
	POST-DUMP	MEAN	0.00	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	0.00
SOUTH BRANCH OF E.R.	PRE-DUMP	MEAN	0.00	1785.71	0.00	29.76	29.76	0.00
		STANDARD ERROR	0.00	925.59	0.00	29.76	29.76	0.00
	POST-DUMP	MEAN	29.76	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	29.76	0.00	0.00	0.00	0.00	0.00
MAIN STEM OF E.R.	PRE-DUMP	MEAN	0.00	892.86	0.00	29.76	0.00	0.00
		STANDARD ERROR	0.00	243.98	0.00	29.76	0.00	0.00
	POST-DUMP	MEAN	0.00	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	0.00
THIMBLE SHOALS	PRE-DUMP	MEAN	0.00	714.29	29.76	29.76	29.76	29.76
		STANDARD ERROR	0.00	243.98	29.76	29.76	29.76	29.76
	POST-DUMP	MEAN	0.00	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	0.00

Figure C5.

ZOOPLANKTON TAXA (#/CU.M.) IN MICROCOSM TREATMENTS

TREATMENT	DAY OF COLLECTION		Nereid sp.	f.e. 1	f.e. Engraulidae	fish larvae	Anchoa sp.	Polonices sp.
CONTROL	PRE-DUMP	MEAN	89.29	0.00	148.81	59.52	238.10	0.00
		STANDARD ERROR	60.99	0.00	54.88	59.52	88.29	0.00
	POST-DUMP	MEAN	0.00	0.00	0.00	0.00	0.00	29.76
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	29.76
SOUTH BRANCH OF E.R.	PRE-DUMP	MEAN	0.00	29.76	233.10	29.76	2916.67	0.00
		STANDARD ERROR	0.00	29.76	109.76	29.76	2845.84	0.00
	POST-DUMP	MEAN	0.00	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	0.00
MAIN STEM OF E.R.	PRE-DUMP	MEAN	0.00	0.00	29.76	148.81	327.38	0.00
		STANDARD ERROR	0.00	0.00	29.76	29.76	85.23	0.00
	POST-DUMP	MEAN	0.00	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	0.00
THIMBLE SHOALS	PRE-DUMP	MEAN	0.00	0.00	178.57	148.81	59.52	0.00
		STANDARD ERROR	0.00	0.00	65.21	71.68	59.52	0.00
	POST-DUMP	MEAN	0.00	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	0.00

Figure C6.

ZOOPLANKTON TAXA (#/CU.M.) IN MICROCOSM TREATMENTS

TREATMENT	DAY OF COLLECTION		bivalve bl	Solinidae	Gast. F	Gast. D	Holothuroid-ea	Bipennaria
CONTROL	PRE-DUMP	MEAN	3363.10	59.52	119.05	178.57	0.00	297.62
		STANDARD ERROR	598.35	37.65	59.52	65.21	0.00	88.29
	POST-DUMP	MEAN	0.00	0.00	0.00	0.00	0.00	29.76
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	29.76
SOUTH BRANCH OF E.R.	PRE-DUMP	MEAN	4761.90	0.00	833.33	0.00	59.52	386.90
		STANDARD ERROR	580.78	0.00	193.80	0.00	59.52	227.83
	POST-DUMP	MEAN	0.00	0.00	59.52	0.00	0.00	29.76
		STANDARD ERROR	0.00	0.00	59.52	0.00	0.00	29.76
MAIN STEM OF E.R.	PRE-DUMP	MEAN	3065.48	29.76	297.62	0.00	59.52	1071.43
		STANDARD ERROR	486.68	29.76	127.66	0.00	59.52	178.57
	POST-DUMP	MEAN	0.00	0.00	0.00	0.00	0.00	59.52
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	37.65
THIMBLE SHOALS	PRE-DUMP	MEAN	3392.86	0.00	238.10	29.76	0.00	386.90
		STANDARD ERROR	461.07	0.00	135.74	29.76	0.00	125.57
	POST-DUMP	MEAN	29.76	0.00	0.00	0.00	0.00	59.52
		STANDARD ERROR	29.76	0.00	0.00	0.00	0.00	37.65

Figure C7.

ZOOPLANKTON TAXA (#/CU.M.) IN MICROCOSM TREATMENTS

TREATMENT	DAY OF COLLECTION		Brachiolaria	Asterias sp.	Foraminifera	Phialucium carolinae	Moerisia lyonsi	Schyphozoan
CONTROL	PRE-DUMP	MEAN	327.38	0.00	0.00	0.00	0.00	29.76
		STANDARD ERROR	71.68	0.00	0.00	0.00	0.00	29.76
	POST-DUMP	MEAN	29.76	29.76	59.52	0.00	0.00	0.00
		STANDARD ERROR	29.76	29.76	37.65	0.00	0.00	0.00
SOUTH BRANCH OF E.R.	PRE-DUMP	MEAN	595.24	0.00	119.05	0.00	0.00	29.76
		STANDARD ERROR	297.62	0.00	75.29	0.00	0.00	29.76
	POST-DUMP	MEAN	0.00	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	0.00
MAIN STEM OF E.R.	PRE-DUMP	MEAN	357.14	89.29	89.29	0.00	0.00	59.52
		STANDARD ERROR	152.92	89.29	60.99	0.00	0.00	59.52
	POST-DUMP	MEAN	119.05	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	59.52	0.00	0.00	0.00	0.00	0.00
THIMBLE SHOALS	PRE-DUMP	MEAN	357.14	148.81	0.00	59.52	0.00	0.00
		STANDARD ERROR	121.99	116.79	0.00	37.65	0.00	0.00
	POST-DUMP	MEAN	0.00	0.00	29.76	89.29	29.76	0.00
		STANDARD ERROR	0.00	0.00	29.76	89.29	29.76	0.00

Figure C8.

ZOOPLANKTON TAXA (#/CU.M.) IN MICROCOSM TREATMENTS

TREATMENT	DAY OF COLLECTION		Mnemiopsis leidy	Sagitta sp.	Phoronid	Penilia
CONTROL	PRE-DUMP	MEAN	0.00	0.00	89.29	0.00
		STANDARD ERROR	0.00	0.00	39.93	0.00
	POST-DUMP	MEAN	0.00	29.76	0.00	0.00
		STANDARD ERROR	0.00	29.76	0.00	0.00
SOUTH BRANCH OF E.R.	PRE-DUMP	MEAN	0.00	0.00	89.29	0.00
		STANDARD ERROR	0.00	0.00	60.99	0.00
	POST-DUMP	MEAN	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00
MAIN STEM OF E.R.	PRE-DUMP	MEAN	0.00	29.76	89.29	29.76
		STANDARD ERROR	0.00	29.76	60.99	29.76
	POST-DUMP	MEAN	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00
THIMBLE SHOALS	PRE-DUMP	MEAN	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00
	POST-DUMP	MEAN	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00

APPENDIX D

Benthic taxa (#/m^2) in microcosm #1. The multivariate (MANOVA) tests of differences between treatments were as follows:

MANOVA	Significant (α=0.05) Treatment-Taxa Combinations
Wilk's = 0.027	Hampton Roads Dump:
F = 1.55	Eteone lactea↓
d.f. = 81, 55	Nemerteans↓
p = 0.04	Protodorvillea kefersteini↓
	Paraprionospio pinnata↓
	Polygordius sp.↓
	Trichophoxus floridana↓
	Hampton Roads Adjacent:
	Brania wellfleetensis↑
	Eteone lactea↑
	Trichophoxus floridana↑
	Control Dump:
	Eteone lactea↑
	Nemerteans↑
	Polygordius spp.↑
	Trichophoxus floridana↑

Notes:

↑Significant increase (α=0.05) in abundance compared to control-adjacent communities.

↓Significant decrease (α=0.05) in abundance compared to control-adjacent communities.

Figure D1.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Ampharete sp.	Ampharete artica	Asychis elongata	Aricidea catherine	Aricidea wassi	Aricidea cerrutti
CONTROL	ADJACENT COMMUNITY	MEAN	0.00	11.90	0.00	4.76	11.90	7.14
		STANDARD ERROR	0.00	5.51	0.00	3.21	4.25	5.13
	DUMP COMMUNITY	MEAN	2.38	9.52	4.76	14.29	0.00	0.00
		STANDARD ERROR	2.38	5.37	3.21	7.46	0.00	0.00
HAMPTON ROADS SEDIMENT	ADJACENT COMMUNITY	MEAN	2.38	7.14	4.76	11.90	0.00	0.00
		STANDARD ERROR	2.38	3.73	3.21	5.51	0.00	0.00
	DUMP COMMUNITY	MEAN	0.00	2.38	7.14	4.76	0.00	0.00
		STANDARD ERROR	0.00	2.38	5.13	3.21	0.00	0.00

TREATMENT	PROXIMITY TO DUMP		Aricidea sp.	Actinaria sp.	Acteocina canaliculata	Ancistrosyllis hartmanae	Anachis lafresnayi	Anemone sp.
CONTROL	ADJACENT COMMUNITY	MEAN	0.00	4.76	0.00	16.67	2.38	2.38
		STANDARD ERROR	0.00	3.21	0.00	5.51	2.38	2.38
	DUMP COMMUNITY	MEAN	0.00	2.38	0.00	9.52	0.00	7.14
		STANDARD ERROR	0.00	2.38	0.00	4.06	0.00	3.73
HAMPTON ROADS SEDIMENT	ADJACENT COMMUNITY	MEAN	2.38	0.00	0.00	16.67	2.38	4.76
		STANDARD ERROR	2.38	0.00	0.00	4.25	2.38	4.76
	DUMP COMMUNITY	MEAN	0.00	0.00	2.38	4.76	0.00	2.38
		STANDARD ERROR	0.00	0.00	2.38	3.21	0.00	2.38

Figure D2.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Ampelisca verrilli	Aglaophamus circinata	Amastigos caperatus	Asteroid sp.	Apoprionospio pygmea	Asychis carolinae
CONTROL	ADJACENT COMMUNITY	MEAN	0.00	0.00	2.38	2.38	2.38	0.00
		STANDARD ERROR	0.00	0.00	2.38	2.38	2.38	0.00
	DUMP COMMUNITY	MEAN	0.00	0.00	11.90	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	7.43	0.00	0.00	0.00
HAMPTON ROADS SEDIMENT	ADJACENT COMMUNITY	MEAN	0.00	2.38	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	2.38	0.00	0.00	0.00	0.00
	DUMP COMMUNITY	MEAN	30.95	0.00	0.00	0.00	0.00	4.76
		STANDARD ERROR	28.45	0.00	0.00	0.00	0.00	4.76

TREATMENT	PROXIMITY TO DUMP		Brania wellfleetensis	Branchiostoma virginiae	Brachyuran megalops	Cirratulidae spp.	Capitella capitata	Crassinella lunulata
CONTROL	ADJACENT COMMUNITY	MEAN	14.29	0.00	2.38	102.38	33.33	0.00
		STANDARD ERROR	5.56	0.00	2.38	21.81	7.73	0.00
	DUMP COMMUNITY	MEAN	2.38	2.38	0.00	135.71	45.24	4.76
		STANDARD ERROR	2.38	2.38	0.00	36.57	19.09	3.21
HAMPTON ROADS SEDIMENT	ADJACENT COMMUNITY	MEAN	16.67	4.76	0.00	107.14	26.19	2.38
		STANDARD ERROR	5.51	3.21	0.00	17.98	8.22	2.38
	DUMP COMMUNITY	MEAN	2.38	0.00	0.00	64.29	35.71	0.00
		STANDARD ERROR	2.38	0.00	0.00	19.62	7.14	0.00

Figure D3.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		*Corambella depressa*	*Crepidula fornicata*	*Cirrophorus furcatus*	*Diopatra cuprea*	*Eteone lactea*	*Eteone heteropoda*
CONTROL	ADJACENT COMMUNITY	MEAN	0.00	2.38	0.00	2.38	11.90	23.81
		STANDARD ERROR	0.00	2.38	0.00	2.38	6.54	9.84
	DUMP COMMUNITY	MEAN	0.00	0.00	2.38	0.00	59.52	0.00
		STANDARD ERROR	0.00	0.00	2.38	0.00	9.50	0.00
HAMPTON ROADS SEDIMENT	ADJACENT COMMUNITY	MEAN	2.38	9.52	0.00	0.00	47.62	11.90
		STANDARD ERROR	2.38	7.32	0.00	0.00	15.36	5.51
	DUMP COMMUNITY	MEAN	0.00	0.00	0.00	0.00	2.38	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	2.38	0.00

TREATMENT	PROXIMITY TO DUMP		*Edotea triloba*	*Glycera americana*	*Glycera dibranchiata*	*Glycera* sp. (Juv.)	Gastropod sp.	*Gyptis brevipalpa*
CONTROL	ADJACENT COMMUNITY	MEAN	0.00	0.00	7.14	0.00	2.38	0.00
		STANDARD ERROR	0.00	0.00	3.73	0.00	2.38	0.00
	DUMP COMMUNITY	MEAN	2.38	11.90	0.00	2.38	2.38	0.00
		STANDARD ERROR	2.38	4.25	0.00	2.38	2.38	0.00
HAMPTON ROADS SEDIMENT	ADJACENT COMMUNITY	MEAN	0.00	4.76	0.00	0.00	4.76	2.38
		STANDARD ERROR	0.00	4.76	0.00	0.00	3.21	2.38
	DUMP COMMUNITY	MEAN	0.00	4.76	0.00	2.38	0.00	0.00
		STANDARD ERROR	0.00	3.21	0.00	2.38	0.00	0.00

Figure D4.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Glycinde sp.	Hemipodeus roseus	Holothuroidean sp.	Harmothoe extenuata	Lepidonotus sublevis	Lumbrineris tenuis
CONTROL	ADJACENT COMMUNITY	MEAN	0.00	4.76	0.00	0.00	0.00	7.14
		STANDARD ERROR	0.00	3.21	0.00	0.00	0.00	3.73
	DUMP COMMUNITY	MEAN	0.00	9.52	0.00	0.00	0.00	38.10
		STANDARD ERROR	0.00	7.32	0.00	0.00	0.00	8.12
HAMPTON ROADS SEDIMENT	ADJACENT COMMUNITY	MEAN	2.38	7.14	2.38	4.76	0.00	26.19
		STANDARD ERROR	2.38	3.73	2.38	3.21	0.00	7.43
	DUMP COMMUNITY	MEAN	0.00	0.00	0.00	0.00	2.38	30.95
		STANDARD ERROR	0.00	0.00	0.00	0.00	2.38	10.82

TREATMENT	PROXIMITY TO DUMP		Lumbrineris fragilis	Lumbrineris acuta	Macroclymene zonalis	Mediomastus ambiseta	Macrophthalmus similis	Maldanid sp.
CONTROL	ADJACENT COMMUNITY	MEAN	2.38	0.00	0.00	69.05	2.38	2.38
		STANDARD ERROR	2.38	0.00	0.00	16.29	2.38	2.38
	DUMP COMMUNITY	MEAN	16.67	0.00	7.14	78.57	4.76	0.00
		STANDARD ERROR	8.22	0.00	3.73	18.98	3.21	0.00
HAMPTON ROADS SEDIMENT	ADJACENT COMMUNITY	MEAN	4.76	2.38	2.38	35.71	4.76	0.00
		STANDARD ERROR	3.21	2.38	2.38	12.74	4.76	0.00
	DUMP COMMUNITY	MEAN	4.76	0.00	3.52	42.86	0.00	0.00
		STANDARD ERROR	3.21	0.00	6.42	9.63	0.00	0.00

Figure D5.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Mercenaria mercenaria	Nemertean sp.	Websteri-nereis tridentata	Nephtys picta	Nephtys pictus	Nucula proxima
CONTROL	ADJACENT COMMUNITY	MEAN	0.00	119.05	0.00	7.14	0.00	14.29
		STANDARD ERROR	0.00	19.53	0.00	5.13	0.00	4.31
	DUMP COMMUNITY	MEAN	4.76	202.38	2.38	7.14	0.00	2.38
		STANDARD ERROR	3.21	39.55	2.38	3.73	0.00	2.38
HAMPTON ROADS SEDIMENT	ADJACENT COMMUNITY	MEAN	0.00	104.76	0.00	4.76	0.00	9.52
		STANDARD ERROR	0.00	20.91	0.00	3.21	0.00	4.06
	DUMP COMMUNITY	MEAN	0.00	64.29	0.00	0.00	2.38	2.38
		STANDARD ERROR	0.00	13.68	0.00	0.00	2.38	2.38

TREATMENT	PROXIMITY TO DUMP		Nereid sp.	Nassarius trivittatus	Oligochaeta spp.	Ophelia denticulata	Ophiuridae sp.	Owenia fusiformis
CONTROL	ADJACENT COMMUNITY	MEAN	2.38	0.00	652.38	0.00	2.38	0.00
		STANDARD ERROR	2.38	0.00	84.03	0.00	2.38	0.00
	DUMP COMMUNITY	MEAN	0.00	0.00	547.62	0.00	0.00	2.38
		STANDARD ERROR	0.00	0.00	89.58	0.00	0.00	2.38
HAMPTON ROADS SEDIMENT	ADJACENT COMMUNITY	MEAN	0.00	2.38	771.43	0.00	0.00	0.00
		STANDARD ERROR	0.00	2.38	135.93	0.00	0.00	0.00
	DUMP COMMUNITY	MEAN	0.00	2.38	442.86	2.38	0.00	0.00
		STANDARD ERROR	0.00	2.38	82.96	2.38	0.00	0.00

Figure D6.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Protodorvillea kefersteini	Paradoneis lyra	Parapionosyllis longicirrata	Polygordius sp.	Polygordius spp.	Pisione remota
CONTROL	ADJACENT COMMUNITY	MEAN	100.00	64.29	9.52	790.48	0.00	0.00
		STANDARD ERROR	18.78	23.10	7.32	133.57	0.00	0.00
	DUMP COMMUNITY	MEAN	135.71	80.95	4.76	904.76	54.76	2.38
		STANDARD ERROR	27.04	17.53	4.76	144.68	54.76	2.38
HAMPTON ROADS SEDIMENT	ADJACENT COMMUNITY	MEAN	145.24	57.14	7.14	523.81	40.48	4.76
		STANDARD ERROR	24.48	11.12	3.73	192.58	40.48	3.21
	DUMP COMMUNITY	MEAN	57.14	21.43	0.00	9.52	0.00	0.00
		STANDARD ERROR	12.68	6.22	0.00	5.37	0.00	0.00

TREATMENT	PROXIMITY TO DUMP		Polydora sp.	Phyllodoce arenae	Phoronis psammophila	Polydora socialis	Paleanotus heteroseta	Pagurus spp.
CONTROL	ADJACENT COMMUNITY	MEAN	4.76	16.67	0.00	0.00	2.38	2.38
		STANDARD ERROR	3.21	6.54	0.00	0.00	2.38	2.38
	DUMP COMMUNITY	MEAN	0.00	7.14	0.00	0.00	7.14	0.00
		STANDARD ERROR	0.00	3.73	0.00	0.00	3.73	0.00
HAMPTON ROADS SEDIMENT	ADJACENT COMMUNITY	MEAN	0.00	7.14	0.00	4.76	7.14	2.38
		STANDARD ERROR	0.00	3.73	0.00	4.76	5.13	2.38
	DUMP COMMUNITY	MEAN	4.76	4.76	2.38	0.00	0.00	0.00
		STANDARD ERROR	4.76	3.21	2.38	0.00	0.00	0.00

Figure D7.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Polydora caulleryi	Polycirrus eximius	Pinnixia sp.	Pycnogonida sp.	Polycirrus minimus	Paraonidae sp.
CONTROL	ADJACENT COMMUNITY	MEAN	0.00	0.00	2.38	2.38	2.38	2.38
		STANDARD ERROR	0.00	0.00	2.38	2.38	2.38	2.38
	DUMP COMMUNITY	MEAN	0.00	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	0.00
HAMPTON ROADS SEDIMENT	ADJACENT COMMUNITY	MEAN	2.38	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	2.38	0.00	0.00	0.00	0.00	0.00
	DUMP COMMUNITY	MEAN	2.38	2.38	0.00	0.00	0.00	0.00
		STANDARD ERROR	2.38	2.38	0.00	0.00	0.00	0.00

TREATMENT	PROXIMITY TO DUMP		Spiophanes bombyx	Sigambra tentaculata	Spisula solidissima	Spionidae sp. (juv.)	Spio setosa	Sipuncula sp.
CONTROL	ADJACENT COMMUNITY	MEAN	16.67	0.00	2.38	2.38	14.29	2.38
		STANDARD ERROR	6.54	0.00	2.38	2.38	4.31	2.39
	DUMP COMMUNITY	MEAN	23.81	4.76	9.52	0.00	30.95	7.14
		STANDARD ERROR	9.19	3.21	5.37	0.00	8.94	7.14
HAMPTON ROADS SEDIMENT	ADJACENT COMMUNITY	MEAN	4.76	0.00	0.00	0.00	21.43	2.38
		STANDARD ERROR	3.21	0.00	0.00	0.00	6.22	2.33
	DUMP COMMUNITY	MEAN	9.52	0.00	0.00	0.00	14.29	2.33
		STANDARD ERROR	4.06	0.00	0.00	0.00	5.56	2.33

Figure D8.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Schisto-meringos caeca	Schisto-meringos rudolphi	Syllidae sp.	Sabellidae sp.	Scalibregma inflatum	Tellina agilis
CONTROL	ADJACENT COMMUNITY	MEAN	2.38	0.00	0.00	2.38	2.38	7.14
		STANDARD ERROR	2.38	0.00	0.00	2.38	2.38	3.73
	DUMP COMMUNITY	MEAN	7.14	2.38	0.00	0.00	0.00	4.76
		STANDARD ERROR	5.13	2.38	0.00	0.00	0.00	4.76
HAMPTON ROADS SEDIMENT	ADJACENT COMMUNITY	MEAN	9.52	0.00	2.38	0.00	0.00	2.38
		STANDARD ERROR	5.37	0.00	2.38	0.00	0.00	2.39
	DUMP COMMUNITY	MEAN	0.00	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	0.00

TREATMENT	PROXIMITY TO DUMP		Turbonilla interrupta	Trichophoxus floridanus	Turbellaria spp.	Trichophoxus epistomus	Unciola irrorata	Unciola serrata
CONTROL	ADJACENT COMMUNITY	MEAN	0.00	19.05	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	7.32	0.00	0.00	0.00	0.00
	DUMP COMMUNITY	MEAN	2.38	140.48	0.00	2.38	2.38	2.38
		STANDARD ERROR	2.38	60.66	0.00	2.38	2.38	2.39
HAMPTON ROADS SEDIMENT	ADJACENT COMMUNITY	MEAN	0.00	116.67	2.38	0.00	0.00	4.76
		STANDARD ERROR	0.00	44.96	2.38	0.00	0.00	4.76
	DUMP COMMUNITY	MEAN	0.00	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	0.00

Figure D9.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Cirratulidae spp.
CONTROL	ADJACENT COMMUNITY	MEAN	0.00
		STANDARD ERROR	0.00
	DUMP COMMUNITY	MEAN	7.14
		STANDARD ERROR	5.13
HAMPTON ROADS SEDIMENT	ADJACENT COMMUNITY	MEAN	0.00
		STANDARD ERROR	0.00
	DUMP COMMUNITY	MEAN	0.00
		STANDARD ERROR	0.00

APPENDIX E

Benthic taxa (#/m^2) in microcosm #2.

The multivariate tests of differences between treatments were as follows:

Treatments	MANOVA	Significant ($\alpha = 0.05$) Treatment-Taxa Combinations
1. Control adj. vs. SB adj. vs. Control dump vs. SB dump	Wilk's = 0.003 F = 3.14 d.f. = 42, 22 p = 0.003	Southern Branch Dump: *Nephtys picta*↓ *Sthenelais boa*↓ *Ensis directus*↓ *Tellina agilus*↓ *Spisula solidissima*↓ *Protohaustorius spp.*↓ Southern Branch Adjacent: *Nephtys picta*↑ Control Dump: *Nephtys picta*↓
2. Control adj. vs. EMS adj. vs. Control dump vs. EMS dump	Wilk's = 0.0004 F = 3.31 d.f. = 51, 13 p = 0.014	Elizabeth River Main-stem Dump: *Capitella capitata*↑ *Nephtys picta*↓ *Polydora socialis*↑ *Spiophanes bombyx*↓
3. Control adj. vs. TS adj. vs. Control dump vs. TS dump	Wilk's = 0.00006 F = 2.96 d.f. = 57, 7 p = 0.10	
4. All dumps	Wilk's = 0.00002 F = 4.08 d.f. = 57, 7 p = 0.04	Southern Branch Dump: *Ensis directus*↓ *Tellina agilis*↓ *Spisula solidissima*↓ *Sthenelais boa*↓ Elizabeth River Main-stem Dump: *Nephtys picta*↓ *Polydora socialis*↑ *Protohaustorius sp.*↓ *Spiophanes bombyx*↓ Thimble Shoal Dump: *Spiophanes bombyx*↑ *Nephtys picta*↑ *Aricidea wassi*↑

5. All adjacent — Wilk's = 0.0017, $F = 0.89$, d.f. = 57, 7, $p = 0.64$

Notes:

†Significant increase ($\alpha=0.05$) in abundance compared to reference values (control-adjacent communities in models 1-3 and 5, control dump in model 4).

↓Significant decrease ($\alpha=0.05$) in abundance compared to reference values.

Figure E1.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Tellina agilis	Ensis directus	Nassarius trivittatus	Capitella capitata	Mediomastus ambiseta	Nemertean spp.
CONTROL	ADJACENT COMMUNITY	MEAN	209.52	457.14	71.43	9.52	4.76	33.33
		STANDARD ERROR	31.87	170.15	30.19	6.02	4.76	8.78
	DUMP COMMUNITY	MEAN	376.19	395.24	42.86	104.76	4.76	14.29
		STANDARD ERROR	78.56	34.14	12.23	45.87	4.76	6.39
SOUTH BRANCH OF E.R.	ADJACENT COMMUNITY	MEAN	342.86	195.24	100.00	38.10	9.52	38.10
		STANDARD ERROR	62.16	81.95	31.08	12.05	6.02	17.56
	DUMP COMMUNITY	MEAN	104.76	185.71	33.33	128.57	14.29	42.86
		STANDARD ERROR	44.67	73.31	18.69	68.71	6.39	14.29
MAIN STEM OF E.R.	ADJACENT COMMUNITY	MEAN	328.57	466.67	90.48	19.05	14.29	19.05
		STANDARD ERROR	82.73	72.53	45.32	6.02	6.39	9.52
	DUMP COMMUNITY	MEAN	323.81	195.24	52.38	114.29	19.05	52.38
		STANDARD ERROR	98.88	29.89	17.17	40.41	9.52	31.66
THIMBLE SHOALS	ADJACENT COMMUNITY	MEAN	528.57	85.71	57.14	61.90	9.52	28.57
		STANDARD ERROR	83.71	30.42	24.47	23.61	6.02	12.78
	DUMP COMMUNITY	MEAN	566.67	176.19	109.52	14.29	9.52	28.57
		STANDARD ERROR	70.92	20.09	40.01	9.76	6.02	7.38

Figure E2.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Spiophanes bombyx	Polydora socialis	Amastigos caperatus	Cirratulidae spp.	Protohaustorius sp.	Nephtys picta
CONTROL	ADJACENT COMMUNITY	MEAN	166.67	204.76	9.52	76.19	485.71	323.81
		STANDARD ERROR	37.19	41.35	9.52	20.43	213.55	67.48
	DUMP COMMUNITY	MEAN	176.19	76.19	0.00	52.38	119.05	128.57
		STANDARD ERROR	11.47	26.26	0.00	29.89	43.28	16.08
SOUTH BRANCH OF E.R.	ADJACENT COMMUNITY	MEAN	119.05	85.71	9.52	33.33	38.10	323.81
		STANDARD ERROR	33.33	23.33	5.02	8.78	14.13	48.75
	DUMP COMMUNITY	MEAN	114.29	228.57	9.52	33.33	85.71	119.05
		STANDARD ERROR	19.52	105.37	5.02	17.17	19.52	17.17
MAIN STEM OF E.R.	ADJACENT COMMUNITY	MEAN	114.29	109.52	4.76	95.24	19.05	304.76
		STANDARD ERROR	36.14	38.63	4.76	36.64	9.52	82.70
	DUMP COMMUNITY	MEAN	76.19	819.05	4.76	71.43	47.62	76.19
		STANDARD ERROR	24.09	158.85	4.76	28.33	21.72	20.43
THIMBLE SHOALS	ADJACENT COMMUNITY	MEAN	219.05	190.48	4.76	38.10	114.29	366.67
		STANDARD ERROR	31.87	53.54	4.76	9.52	97.31	69.76
	DUMP COMMUNITY	MEAN	223.81	47.62	4.76	52.38	742.86	257.14
		STANDARD ERROR	37.92	9.52	4.76	17.17	238.70	45.48

Figure E3.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Streblospio benedicti	Aricidea wassi	Pandora trilineata	Natica pusilla	Asabellides oculata	Spisula solidissima
CONTROL	ADJACENT COMMUNITY	MEAN	0.00	19.05	33.33	52.38	66.67	2057.14
		STANDARD ERROR	0.00	9.52	8.78	13.64	35.12	863.50
	DUMP COMMUNITY	MEAN	0.00	19.05	14.29	71.43	138.10	1761.90
		STANDARD ERROR	0.00	14.13	5.39	14.29	29.89	458.02
SOUTH BRANCH OF E.R.	ADJACENT COMMUNITY	MEAN	0.00	52.38	28.57	104.76	100.00	809.52
		STANDARD ERROR	0.00	17.17	7.38	34.34	25.29	295.88
	DUMP COMMUNITY	MEAN	4.76	23.81	23.81	47.62	166.67	314.29
		STANDARD ERROR	4.76	8.78	15.50	22.94	52.90	63.46
MAIN STEM OF E.R.	ADJACENT COMMUNITY	MEAN	0.00	47.62	33.33	80.95	85.71	728.57
		STANDARD ERROR	0.00	12.05	8.78	11.47	24.47	272.73
	DUMP COMMUNITY	MEAN	0.00	14.29	23.81	47.62	61.90	800.00
		STANDARD ERROR	0.00	14.29	13.64	26.26	15.50	243.67
THIMBLE SHOALS	ADJACENT COMMUNITY	MEAN	0.00	90.48	23.81	95.24	147.62	266.67
		STANDARD ERROR	0.00	28.01	11.47	32.72	42.64	75.11
	DUMP COMMUNITY	MEAN	0.00	47.62	14.29	100.00	123.81	1247.62
		STANDARD ERROR	0.00	17.56	9.76	20.54	12.05	460.92

Figure E4.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Ampelisca verrilli	Anemone sp.	Polynoidae sp.	Magelona sp.	Veneridae sp.	Cancer irroratus
CONTROL	ADJACENT COMMUNITY	MEAN	147.62	33.33	0.00	0.00	33.33	0.00
		STANDARD ERROR	119.73	8.78	0.00	0.00	17.17	0.00
	DUMP COMMUNITY	MEAN	19.05	19.05	0.00	14.29	66.67	0.00
		STANDARD ERROR	9.52	14.13	0.00	9.76	20.43	0.00
SOUTH BRANCH OF E.R.	ADJACENT COMMUNITY	MEAN	71.43	19.05	0.00	4.76	28.57	0.00
		STANDARD ERROR	65.88	9.52	0.00	4.76	10.43	0.00
	DUMP COMMUNITY	MEAN	133.33	33.33	4.76	4.76	19.05	4.76
		STANDARD ERROR	127.70	17.17	4.76	4.76	9.52	4.76
MAIN STEM OF E.R.	ADJACENT COMMUNITY	MEAN	4.76	4.76	4.76	9.52	19.05	0.00
		STANDARD ERROR	4.76	4.76	4.76	6.02	9.52	0.00
	DUMP COMMUNITY	MEAN	19.05	14.29	0.00	0.00	14.29	0.00
		STANDARD ERROR	12.05	6.39	0.00	0.00	6.39	0.00
THIMBLE SHOALS	ADJACENT COMMUNITY	MEAN	19.05	19.05	0.00	14.29	9.52	4.76
		STANDARD ERROR	12.05	9.52	0.00	6.39	6.02	4.76
	DUMP COMMUNITY	MEAN	47.62	14.29	0.00	19.05	19.05	0.00
		STANDARD ERROR	42.16	6.39	0.00	6.02	14.13	0.00

Figure E5.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Crangon septemspinosa	Phyllodoce arenae	Leitoscoloplos fragilis	Glycera sp. (juv.)	Owenia fusiformis	Parvilucina multilineata
CONTROL	ADJACENT COMMUNITY	MEAN	0.00	0.00	19.05	23.81	4.76	0.00
		STANDARD ERROR	0.00	0.00	12.05	8.78	4.76	0.00
	DUMP COMMUNITY	MEAN	0.00	0.00	14.29	14.29	4.76	0.00
		STANDARD ERROR	0.00	0.00	9.76	6.39	4.76	0.00
SOUTH BRANCH OF E.R.	ADJACENT COMMUNITY	MEAN	0.00	4.76	9.52	28.57	4.76	4.76
		STANDARD ERROR	0.00	4.76	9.52	10.43	4.76	4.76
	DUMP COMMUNITY	MEAN	4.76	4.76	19.05	14.29	0.00	0.00
		STANDARD ERROR	4.76	4.76	9.52	9.76	0.00	0.00
MAIN STEM OF E.R.	ADJACENT COMMUNITY	MEAN	0.00	0.00	14.29	4.76	4.76	0.00
		STANDARD ERROR	0.00	0.00	5.39	4.76	4.76	0.00
	DUMP COMMUNITY	MEAN	0.00	0.00	4.76	33.33	0.00	9.52
		STANDARD ERROR	0.00	0.00	4.76	11.47	0.00	6.02
THIMBLE SHOALS	ADJACENT COMMUNITY	MEAN	0.00	0.00	9.52	23.81	0.00	4.76
		STANDARD ERROR	0.00	0.00	5.02	13.64	0.00	4.75
	DUMP COMMUNITY	MEAN	0.00	0.00	14.29	28.57	0.00	4.75
		STANDARD ERROR	0.00	0.00	14.29	7.38	0.00	4.76

Figure E6.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Polygordius sp	Macroclymene zonalis	Nucula proxima	Sthenelais boa	Odostomia sp.	Scolelepis bousfieldi
CONTROL	ADJACENT COMMUNITY	MEAN	28.57	9.52	0.00	47.62	0.00	9.52
		STANDARD ERROR	12.78	6.02	0.00	19.05	0.00	9.52
	DUMP COMMUNITY	MEAN	0.00	4.76	0.00	42.66	0.00	0.00
		STANDARD ERROR	0.00	4.76	0.00	9.76	0.00	0.00
SOUTH BRANCH OF E.R.	ADJACENT COMMUNITY	MEAN	28.57	4.76	9.52	23.81	4.76	0.00
		STANDARD ERROR	23.33	4.76	5.02	13.64	4.76	0.00
	DUMP COMMUNITY	MEAN	0.00	4.76	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	4.76	0.00	0.00	0.00	0.00
MAIN STEM OF E.R.	ADJACENT COMMUNITY	MEAN	33.33	4.76	4.76	14.29	4.76	0.00
		STANDARD ERROR	23.81	4.76	4.76	6.39	4.76	0.00
	DUMP COMMUNITY	MEAN	28.57	0.00	19.05	28.57	0.00	0.00
		STANDARD ERROR	18.07	0.00	12.05	7.38	0.00	0.00
THIMBLE SHOALS	ADJACENT COMMUNITY	MEAN	33.33	0.00	0.00	38.10	0.00	0.00
		STANDARD ERROR	18.69	0.00	0.00	17.56	0.00	0.00
	DUMP COMMUNITY	MEAN	9.52	4.76	4.76	19.05	0.00	0.00
		STANDARD ERROR	6.02	4.76	4.76	9.52	0.00	0.00

Figure E7.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Ampharete arctica	Trichophoxus floridanus	Onuphis eremita	Acteocina canaliculata	Turbonilla interrupta	Spio setosa
CONTROL	ADJACENT COMMUNITY	MEAN	4.76	61.90	42.86	0.00	14.29	9.52
		STANDARD ERROR	4.76	61.90	21.82	0.00	6.39	6.02
	DUMP COMMUNITY	MEAN	0.00	23.81	33.33	0.00	4.76	9.52
		STANDARD ERROR	0.00	23.81	23.81	0.00	4.76	9.52
SOUTH BRANCH OF E.R.	ADJACENT COMMUNITY	MEAN	4,76	4.76	9.52	0.00	4.76	0.00
		STANDARD ERROR	4.76	4.76	5.02	0.00	4.76	0.00
	DUMP COMMUNITY	MEAN	33.33	4.76	0.00	0.00	0.00	0.00
		STANDARD ERROR	18.69	4.76	0.00	0.00	0.00	0.00
MAIN STEM OF E.R.	ADJACENT COMMUNITY	MEAN	0.00	4.76	4.76	0.00	4.76	14.29
		STANDARD ERROR	0.00	4.76	4.76	0.00	4.76	9.76
	DUMP COMMUNITY	MEAN	14.29	4.76	9.52	0.00	0.00	9.52
		STANDARD ERROR	6.39	4.76	6.02	0.00	0.00	6.02
THIMBLE SHOALS	ADJACENT COMMUNITY	MEAN	4.76	14.29	33.33	4.76	9.52	0.00
		STANDARD ERROR	4.76	9.76	11.47	4.76	6.02	0.00
	DUMP COMMUNITY	MEAN	4.76	28.57	28.57	242.86	14.29	9.52
		STANDARD ERROR	4.76	18.07	7.38	37.43	9.76	9.52

Figure E8.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Lumbrineris fragilis	Glycera dibranchiata	Aricidae catherinae	Apopriono-spio pygmaea	Oligochaeta spp.	Phoronis architecta
CONTROL	ADJACENT COMMUNITY	MEAN	4.76	0.00	4.76	14.29	9.52	14.29
		STANDARD ERROR	4.76	0.00	4.76	6.39	9.52	9.76
	DUMP COMMUNITY	MEAN	0.00	0.00	33.33	0.00	4.76	9.52
		STANDARD ERROR	0.00	0.00	15.50	0.00	4.76	9.52
SOUTH BRANCH OF E.R.	ADJACENT COMMUNITY	MEAN	4.76	0.00	0.00	0.00	19.05	0.00
		STANDARD ERROR	4.76	0.00	0.00	0.00	19.05	0.00
	DUMP COMMUNITY	MEAN	4.76	0.00	0.00	0.00	9.52	4.76
		STANDARD ERROR	4.76	0.00	0.00	0.00	9.52	4.76
MAIN STEM OF E.R.	ADJACENT COMMUNITY	MEAN	0.00	0.00	0.00	4.76	23.81	4.76
		STANDARD ERROR	0.00	0.00	0.00	4.76	15.50	4.76
	DUMP COMMUNITY	MEAN	0.00	14.29	4.76	0.00	9.52	4.76
		STANDARD ERROR	0.00	9.76	4.76	0.00	6.02	4.76
THIMBLE SHOALS	ADJACENT COMMUNITY	MEAN	9.52	19.05	4.76	4.76	19.05	4.76
		STANDARD ERROR	6.02	9.52	4.76	4.76	9.52	4.76
	DUMP COMMUNITY	MEAN	9.52	9.52	0.00	0.00	0.00	4.76
		STANDARD ERROR	9.52	6.02	0.00	0.00	0.00	4.76

Figure E9.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Notomastus hemipodus	Cirrophorus furcatus	Glycera americana	Cylinchnella bidentata	Polynoidae sp.	Lumbrineris tenuis
CONTROL	ADJACENT COMMUNITY	MEAN	0.00	14.29	0.00	4.76	0.00	0.00
		STANDARD ERROR	0.00	6.39	0.00	4.76	0.00	0.00
	DUMP COMMUNITY	MEAN	0.00	19.05	4.76	23.81	0.00	0.00
		STANDARD ERROR	0.00	9.52	4.76	13.64	0.00	0.00
SOUTH BRANCH OF E.R.	ADJACENT COMMUNITY	MEAN	0.00	4.76	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	4.76	0.00	0.00	0.00	0.00
	DUMP COMMUNITY	MEAN	0.00	0.00	0.00	14.29	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	9.76	0.00	0.00
MAIN STEM OF E.R.	ADJACENT COMMUNITY	MEAN	0.00	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	0.00
	DUMP COMMUNITY	MEAN	0.00	9.52	0.00	9.52	0.00	4.76
		STANDARD ERROR	0.00	6.02	0.00	6.02	0.00	4.76
THIMBLE SHOALS	ADJACENT COMMUNITY	MEAN	4.76	4.76	0.00	0.00	0.00	0.00
		STANDARD ERROR	4.76	4.76	0.00	0.00	0.00	0.00
	DUMP COMMUNITY	MEAN	4.76	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	4.76	0.00	0.00	0.00	0.00	0.00

Figure E10.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Rictaxis punctostriatus	Mercenaria mercenaria	Eteone heteropoda	Pseudoleptocuma minor	Polydora ligni	Nephtyidae sp. (juv.)
CONTROL	ADJACENT COMMUNITY	MEAN	0.00	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	0.00
	DUMP COMMUNITY	MEAN	0.00	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	0.00
SOUTH BRANCH OF E.R.	ADJACENT COMMUNITY	MEAN	0.00	0.00	4.76	4.76	0.00	0.00
		STANDARD ERROR	0.00	0.00	4.76	4.76	0.00	0.00
	DUMP COMMUNITY	MEAN	0.00	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	0.00
MAIN STEM OF E.R.	ADJACENT COMMUNITY	MEAN	0.00	0.00	0.00	0.00	4.76	28.57
		STANDARD ERROR	0.00	0.00	0.00	0.00	4.76	28.57
	DUMP COMMUNITY	MEAN	0.00	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	0.00	0.00	0.00	0.00	0.00
THIMBLE SHOALS	ADJACENT COMMUNITY	MEAN	4.76	0.00	0.00	0.00	0.00	0.00
		STANDARD ERROR	4.76	0.00	0.00	0.00	0.00	0.00
	DUMP COMMUNITY	MEAN	0.00	4.76	0.00	0.00	0.00	0.00
		STANDARD ERROR	0.00	4.76	0.00	0.00	0.00	0.00

Figure E11.

BENTHIC TAXA (#/SQ.M.) IN MICROCOSM TREATMENTS

TREATMENT	PROXIMITY TO DUMP		Diopatra cuprea	Mysella planulata
CONTROL	ADJACENT COMMUNITY	MEAN	0.00	4.76
		STANDARD ERROR	0.00	4.76
	DUMP COMMUNITY	MEAN	0.00	0.00
		STANDARD ERROR	0.00	0.00
SOUTH BRANCH OF E.R.	ADJACENT COMMUNITY	MEAN	0.00	0.00
		STANDARD ERROR	0.00	0.00
	DUMP COMMUNITY	MEAN	0.00	0.00
		STANDARD ERROR	0.00	0.00
MAIN STEM OF E.R.	ADJACENT COMMUNITY	MEAN	4.76	0.00
		STANDARD ERROR	4.76	0.00
	DUMP COMMUNITY	MEAN	0.00	0.00
		STANDARD ERROR	0.00	0.00
THIMBLE SHOALS	ADJACENT COMMUNITY	MEAN	0.00	0.00
		STANDARD ERROR	0.00	0.00
	DUMP COMMUNITY	MEAN	0.00	0.00
		STANDARD ERROR	0.00	0.00

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